National Flood Hazard Mitigation Priorities

Technical Report

IAG | RR-01-1448 | April 2022

Executive Summary

Australia has an extensive network of floodplains; these range from those associated with small local urban drainage systems through to the vast expanse of floodplain associated with the Murray Darling River. While there is often a good understanding of flood risk at a local government or state level scale, there are only limited studies that have evaluated the flood hazard mitigation projects across Australia and then ranked them in order of priority.

IAG has long been an advocate for a stronger focus on prevention and mitigation of floodplains to minimise the impact of floods on Australian communities. It is acknowledge that there is finite funding available to put towards mitigation projects and the difficult question is where and how is mitigation funding best spent. As a result, IAG commissioned Rhelm to develop a set of National Flood Hazard Mitigation Priorities. The method for setting priorities involves identifying areas with high flood risk, where there are potential flood mitigation measures that could be implemented to reduce this risk and then ranking the practicality and cost benefit of each area.

This report is a technical report that accompanies a series of flood summaries or "snapshots" that have been prepared for each of the short-listed areas identified to be affected by high flood risk.

There are two key components of this report:

- Identification of potential structural flood mitigation measures (also known as flood modification measures in some jurisdictions) in short-listed floodplains across the country, and an economic assessment of these measures;
- A review of potential property level mitigation measures, such as flood resilience and house raising, and an economic assessment of these measures.

While this report focuses on these two elements of flood risk mitigation, they should ideally be considered in the wider context of flood risk mitigation. This would include consideration of additional mitigation measures such as emergency response and appropriate planning controls, within an appropriate flood risk mitigation process similar to that identified in Section 1.4.

Flood Mitigation Measures in Short-Listed Floodplains

Strategic level flood mitigation measures have been identified across nine short-listed floodplains in Australia. The broad process for this assessment is summarised in Figure i.

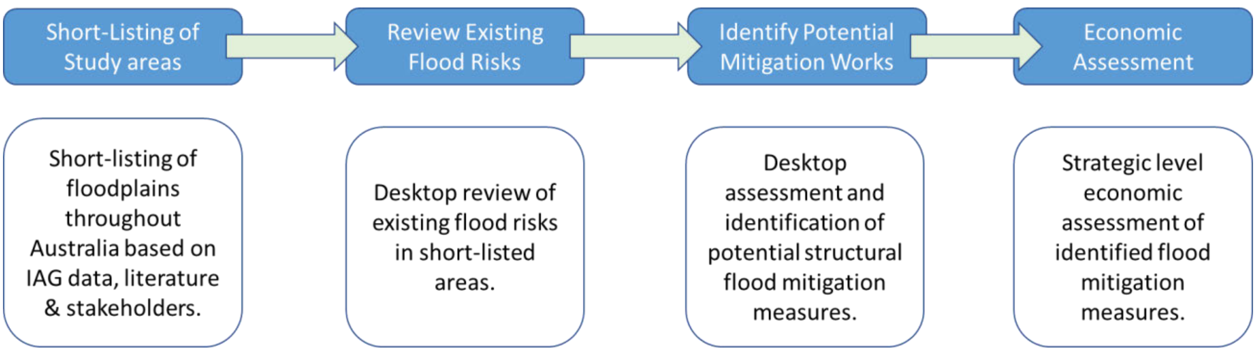

Figure i. Assessment Process

The short-listing process considered not only the potential flood damages, but also the potential feasibility of mitigation measures and the socio-economic context of the various areas. The details of the long-list and subsequent short-list areas are discussed in further detail in Section 3.

The short-listed floodplains are identified in Figure ii.

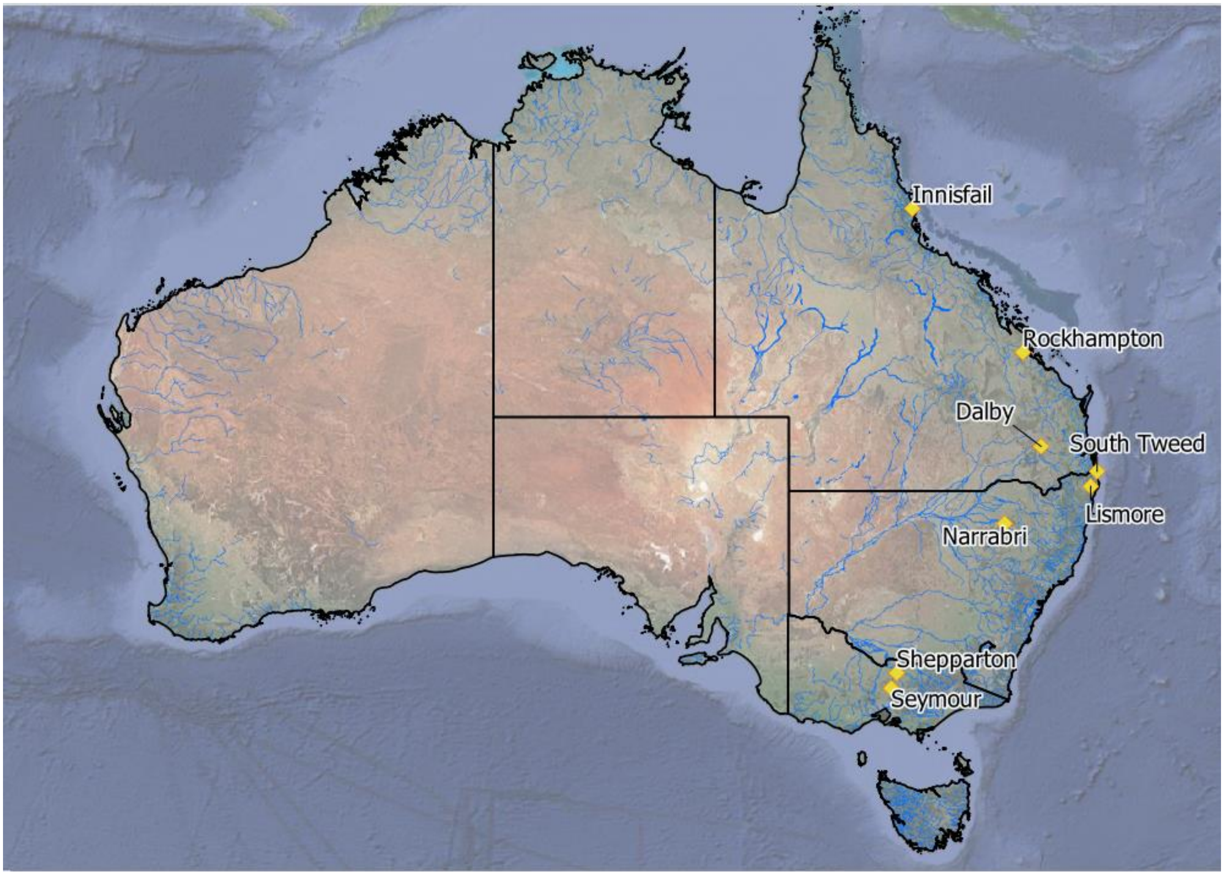

Figure ii. Short-Listed Floodplains

A desktop review of these floodplains was undertaken, and potential structural modification measures were identified. A summary of all the floodplains and identified measures are provided in Table ii.

A review of the relative effectiveness of the mitigation measures in reducing flood affected properties is provided in Figure iii, while the economic analysis results are provided in Figure iv and Figure v.

Benefit cost ratio (BCR) values in excess of 1 are where the present value of the benefits exceed the costs, and therefore the option would be considered economically viable. All mitigation works identified in this report have a BCR greater than 1.

2022 Flood Events

The analysis undertaken in this report was finalised in August 2021, prior to the flooding in Queensland and NSW in early 2022. We acknowledge that there is an evolving attitude to flood risk and mitigation in Queensland and NSW, including in some of the communities identified in this report. There is also ongoing work in some communities which may influence mitigation measures that are identified.

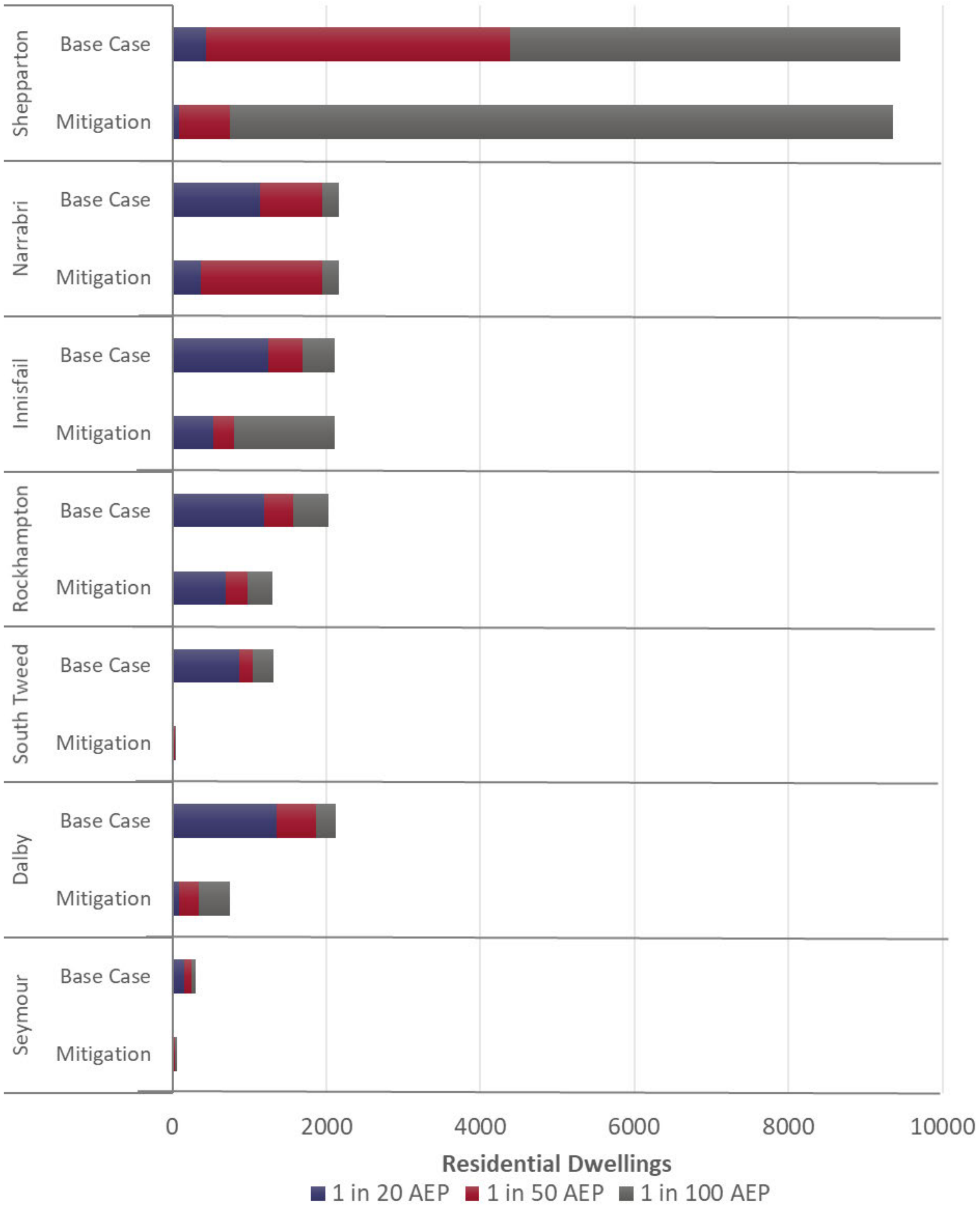

Figure iii. Number of Residential Dwellings Affected by Flooding and Protected by Identified Potential Mitigation

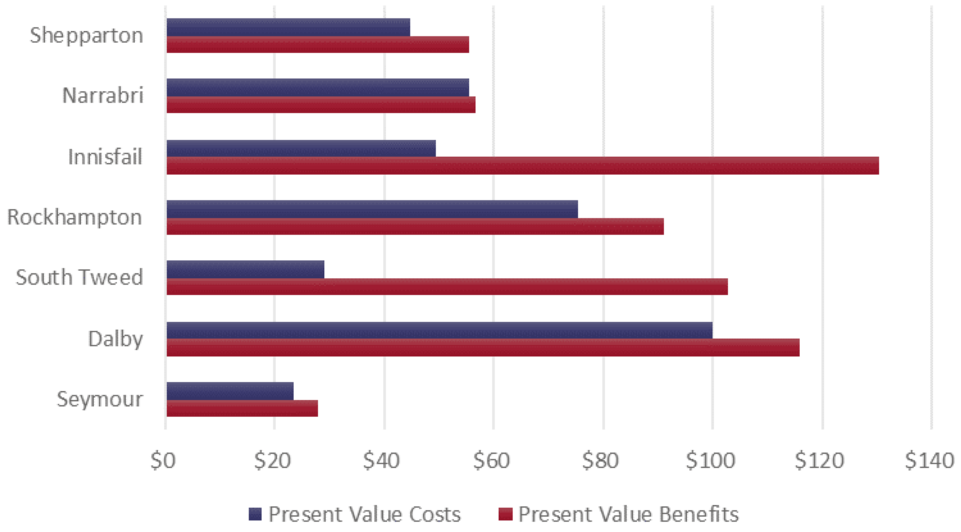

Figure iv. Comparison of Benefits and Costs for Identified Mitigation Measures

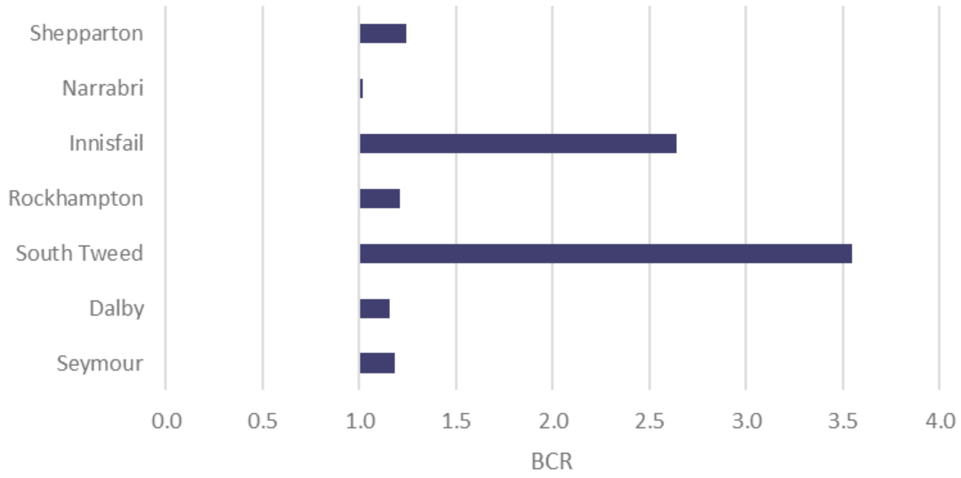

Figure v. Benefit Cost Ratio for Identified Mitigation Measures

Property Level Mitigation

Flood risk management includes the consideration of not just structural flood mitigation/modification options, but also wider consideration of property level mitigation and emergency management. As part of this overall project, a review was undertaken on a sub-set of property level mitigation alternatives, namely:

- Flood Resilience;
- House Raising;
- Land Swap.

The focus of the assessment for flood resilience and house raising is on existing dwellings, rather than new development.

To support the analysis, six representative areas were chosen to undertake testing of the various alternatives. These areas were high ranked locations from the short-listing process in Section 3, and include:

- Coraki;
- Woodburn;
- Smithtown;
- Noosaville;
- Narrabeen; and,
- Wollongong.

Each of these locations have a range of different types of flood behaviour and types of development. Coraki, Woodburn and Smithtown are all small townships on large river systems and have relatively frequent and deep flooding. The Narrabeen suburb is primarily influenced by flooding from Narrabeen Lagoon, which tends to be relatively long duration inundation. Wollongong, by comparison, is more flash flooding generated by the Illawarra Escarpment.

The above analysis has largely demonstrated that flood resilience and house raising are largely viable where property floor levels are at or below the 1 in 10 AEP. This may be further improved if a large scale program were adopted that could achieve cost efficiencies. However, both property level options only deal with a portion of the overall flood damages, as well as the risks associated with the property being located in the floodplain. A high level comparison of the flood risk components that the options address is presented in Table i.

Land swap provides the most "comprehensive" reduction in flood damages and flood risks, but has a lower economic performance if it is undertaken as a pre-emptive measure. However, as noted, there are additional considerations that have not been included in this analysis, including:

- The reduction in risk to life for the household, as well as the evacuation considerations and demands on emergency services;
- The potential improvement in flood conveyance as a result of the removal of the property, and the associated benefits to other properties as a result;
- For very hazardous flood flows, the potential risk of partial or full structural failure of the dwelling;
- Where the house can be relocated at relatively low cost, rather than the need to construct a new house;
- Following a flood event, where the existing dwelling has suffered significant structural damage.

Under these types of conditions, land swap may be a viable alternative to be considered.

A sensitivity analysis was undertaken on the scenario where a property experience significant structural damages and requires replacement following a flood event. If the land swap were to occur at that point in time, then the analysis suggests that it would be viable for a floor level less than 1 in 10 AEP, and potential marginal for a 1 in 10 to 1 in 20 AEP. As per the discussion above, other considerations (such as the risk to life and flood conveyance improvements) may result in an improved outcome.

Table i. Property Mitigation Comparison

Mitigation Type	Direct Damage		Indirect Damages		Intangibles	
	Building Damages	Contents Damage	Cleanup Costs	Relocation	Risk to Life	Other
Flood Resilient Building (Retrofit)						
House Raising						
Land Swap						

Low/ No Reduction

Partial Reduction

Large Reduction

Table ii. Summary of Mitigation Measures

Floodplain	Item	Description
Shepparton	Level of Design	Strategic. While the mitigation was assessed in 2002 (with a higher protection), no update to this assessment has been undertaken.
	Flood Mitigation Performance	Targeting a 1 in 50 AEP protection for those areas protected by the levees. May be required to lower this protection if negative flood impacts.
	Cost Estimate	**$47.7M ($40M - $50M)** Strategic only.
	AAD Reduction due to Mitigation	**$5M**
	BCR	**1.2**
	Constraints	• Potential environmental constraints, particularly for the floodway • Uncertain on community acceptance of the scheme.
	Further Work Required	A flood risk management study (as per Section 1.4), to undertake appropriate optioneering and community engagement.
Narrabri	Level of Design	Strategic. No formal modelling or investigation of mitigation options undertaken.
	Flood Mitigation Performance	Targeting a 1 in 10 to 1 in 20 AEP protection for a number of areas in Narrabri. Potential for flood impacts on adjacent properties – modelling required to refine scheme.
	Cost Estimate	**$59.1M ($55M-$65M)**
	AAD Reduction due to Mitigation	**$5M**
	BCR	**1.0**
	Constraints	• Potential flood afflux • Several road crossings and interfaces with private properties • Environmental considerations are uncertain.

Floodplain	Item	Description
	Further Work Required	Floodplain risk management study and plan to be completed (currently in progress), including appropriate optioneering and community engagement.
Innisfail	Level of Design	Strategic. While the mitigation was assessed in 2014 (with a higher protection), no update to this assessment has been undertaken.
	Flood Mitigation Performance	Targeting a 1 in 50 AEP protection for those areas protected by the levees. May be required to lower this protection if negative flood impacts are identified.
	Cost Estimate	**$52.7M ($50M-$60M)**
	AAD Reduction due to Mitigation	**$12M**
	BCR	**2.6**
	Constraints	• Potential environmental constraints, particularly for the dredging • Challenges with some levees crossing creeks and roads. Flood gates required • Uncertain on community acceptance of the scheme • Potential flood afflux of the scheme, further investigation required.
	Further Work Required	A flood risk management study (as per Section 1.4), to undertake appropriate optioneering and community engagement.
Rockhampton	Level of Design	Detailed design, ready for tender (pending funding).
	Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levees.
	Cost Estimate	**$80.4M (based on detailed estimates)**
	AAD Reduction due to Mitigation	**$8M**
	BCR	**1.2**
	Constraints	• Relatively low, given EAR undertaken.
	Further Work Required	Minimal, ready to be tendered.
South Tweed	Level of Design	Strategic.
	Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levee.
	Cost Estimate	**$30.9M ($25M-$35M)**
	AAD Reduction due to Mitigation	**$9M**
	BCR	**3.5**
	Constraints	• Potential environmental constraints, particularly for Phillip Parade extension • There may be further engineering constraints, particularly for the Phillip Parade extension.
	Further Work Required	A flood risk management study (as per Section 1.4) has been undertaken. Further investigation and optioneering required on the levee options.
Dalby	Level of Design	Strategic. Further analysis required to understand relative benefits of proposed options

Floodplain	Item	Description
	Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levee, uncertain for the flowpath.
	Cost Estimate	**$107M ($100M-$110M)**
	AAD Reduction due to Mitigation	**$11M**
	BCR	**1.2**
	Constraints	• Potential environmental constraints, particularly for the excavation • Land acquisition issues along the flowpath. • Uncertain on community acceptance of the scheme • Potential flood afflux of the scheme, further investigation required.
	Further Work Required	A flood risk management study (as per Section 1.4), to undertake appropriate optioneering and community engagement.
Seymour	Level of Design	Detailed
	Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levee.
	Cost Estimate	**$25M** Detailed
	AAD Reduction due to Mitigation	**$2M**
	BCR	**1.2**
	Constraints	Potential community objection, although it is understood that this primarily was associated with the funding rather than the levee itself.
	Further Work Required	Finalise detailed design

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Appendices

Appendix A – Short-Listed Areas

Appendix B - Economic Methodology

Appendix C – Cost Estimates

Acronyms

AAD	Annual Average Damage
ABS	Australian Bureau of Statistics
AEP	Annual Exceedance Probability
BCR	Benefit Cost Ratio
FPRMS	Floodplain Risk Management Study
FPRMSP	Floodplain Risk Management Study and Plan
GIS	Geographic Information System
IAG	Insurance Australia Group
ICA	Insurance Council of Australia
MCA	Multi-Criteria Analysis
SA	Statistical Areas

1 Introduction

1.1 Overview

While there is often a good understanding of flood risk at a local government or state level scale, there are only limited studies that have looked into the general flood hazard mitigation priorities across Australia. The Insurance Council of Australia (ICA, 2019) undertook an analysis of ICA damage databases and identified a number of priority areas. However, the potential mitigation measures were relatively high level or were options that focused on data collection (such as property-based databases).

IAG has long been an advocate for a stronger focus on prevention and mitigation to minimise the impact of floods on Australian communities. It is also acknowledge that there is finite funding available to put towards mitigation projects and the difficult question is where and how is mitigation funding best spent. As a result, IAG commissioned Rhelm to develop a set of National Flood Hazard Mitigation Priorities.

In addition to wider floodplain-based mitigation, there are a number of potential measures that can be adopted to mitigate the impacts of flooding at the individual property scale. IAG commissioned Rhelm to further understand the potential economic viability of these property level mitigation measures.

This report is a technical report that accompanies flood summaries or "snapshots" that have been prepared for each of the short-listed areas.

There are two key components of this report:

- Identification of potential structural flood mitigation measures (also known as flood modification measures in some jurisdictions) in short-listed floodplains across the country, and an economic assessment of these measures;
- A review of potential property level mitigation measures, such as flood resilience and house raising, and an economic assessment of these measures.

1.2 Key Objectives

The key objectives of the project are:

- To identify high risk flood areas within Australia;
- To identify and evaluate high level strategic structural mitigation measures at a number of high-risk flood areas in Australia to mitigate flooding. These measures will:
    - result in a substantive reduction in the flood risk for an area;
    - be projects of a scale that can generally not be undertaken by local government/ local agency alone, but exclude catchments where effective flood mitigation would likely be in excess of $150M and would require significant timeframes for planning;
    - provide wider scale economic benefits (beyond property damages);
    - be viable projects (e.g. viable from an engineering, environmental and social perspective etc);
    - Rely on existing studies and options were possible, to ensure the identified measures are evidence based and broadly supported by local and state governments.
- To undertake economic analysis on the identified mitigation measures to understand their potential viability.

In addition to these objectives, the potential viability of property level mitigation measures (as a retrofit to existing properties) was investigated.

1.3 Assessment Process

The study undertook the prioritisation and investigation process in four key stages. These are summarised in Figure 1. The short-listing process was based on a combination of the flood risk and potential mitigation viability in flood affected areas across the country.

These short-listed areas should not be considered an exclusive list. There are numerous flood-affected areas throughout the country. Different short-listing processes or criteria may result in a different outcome, together with different objectives (such as the inclusion of socio-economic factors in this process).

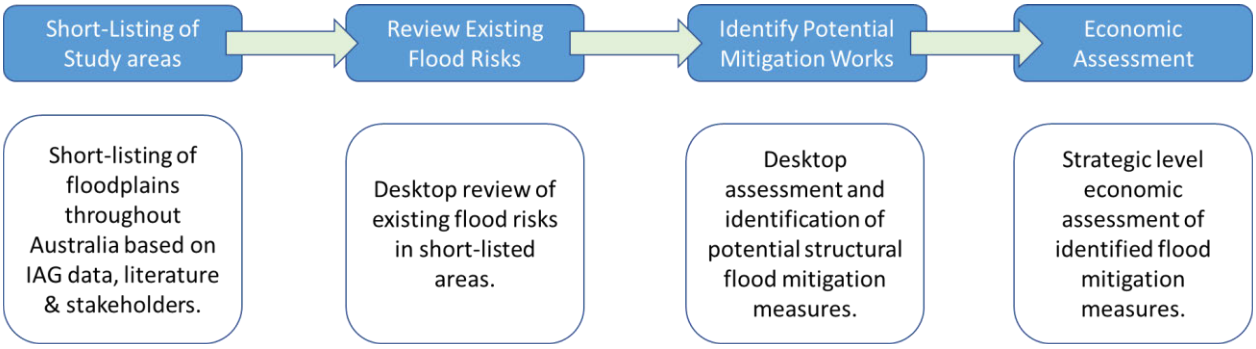

Figure 1. Overview of Assessment Process - Prioritisation and Mitigation Measures

1.4 Flood Risk Management

Flood risk management deals with existing, future and residual flood risk within a community. This can be undertaken through a range of risk mitigation measures, such as structural flood mitigation, emergency management and property-based mitigation (such as planning controls and property based mitigation). This should be done in a collaborative manner with the community and key stakeholders, and with due consideration to environmental and heritage values. An overview of the National flood risk management framework, as per Handbook 7, is provided in Figure 2.

While this report focuses on potential structural mitigation for identified study areas, and some property-based mitigation, these should be considered as a part of any wider flood risk management strategy. While some of the study areas have progressed further along the risk management process, others are still early within this process. The general progress and level of investigation within each of the study areas has been identified in Section 4.

1.5 2022 Flood Events

The analysis undertaken in this report was finalised in August 2021, prior to the flooding in Queensland and NSW in early 2022. We acknowledge that there is an evolving attitude to flood risk and mitigation in Queensland and NSW, including in some of the communities identified in this report. There is also ongoing work in some communities which may influence mitigation measures that are identified.

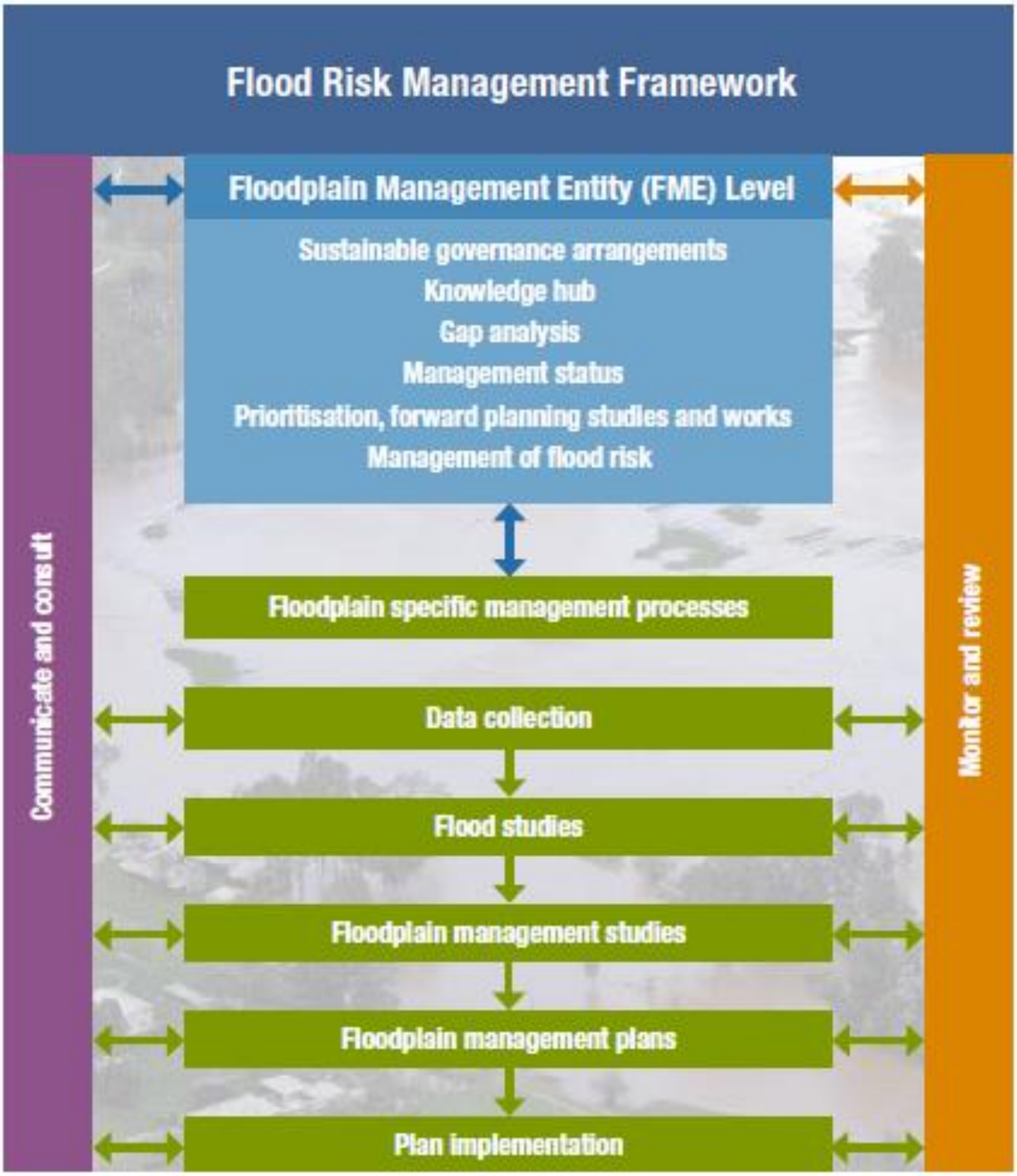

Figure 2. Flood Risk Management Framework (Source : AEMI, 2013)

2 Available Data

2.1 IAG Residential Data

IAG provided key summarised information from their damages databases for the study areas. This information was provided at an Australian Bureau of Statistics (ABS) Statistical Areas (SA) SA4, SA3, SA2, SA1 and Mesh Block scale[1]. Key information provided included:

- Annual Average Damage (AAD) for building and contents;
- Number of addresses impacted across a range of AEP events (noting that not all of these were residential), namely:
  - < 1 in 20 AEP;
  - 1 in 20 to 1 in 50 AEP;
  - 1 in 50 to 1 in 100 AEP;
  - 1 in 100 to 1 in 500 AEP;
  - 1 in 500 AEP to 1 in 10,000 AEP;
  - > 1 in 10,000 AEP.
- Number of residential dwellings identified within the mesh block.

This information was provided for three climate change scenarios:

- CC0 – Current climate conditions (approx 1.2 degrees above pre-industrial era);
- CC2 – 2 degree increase in temperatures relative to pre-industrial era;
- CC3 – 3 degree increase in temperatures relatively to pre-industrial era.

This data represents a key input to this project. Assumptions on other damages (such as commercial and industrial, as outlined in Appendix B) are tied to the underlying residential damage estimate provided by IAG.

2.2 GIS Data

In addition to the information provided by IAG, the following spatial data sources were collated for the project.

Table 1. Summary of Spatial Data

Data Type	Location	Reference/ Comment
Terrain	Shepparton/Seymour	Vicmap™ Elevation DEM 10m (DELWP, 2020)
	Narrabri	NARRABRI, 2kmx2km 5 metre Resolution Digital Elevation Model (NSW Spatial Services, 2016)
	Other Locations	Digital Elevation Model (DEM) of Australia derived from LiDAR 5 Metre Grid (Geoscience Australia, 2015)
Land-Use Planning	Victorian	Vicmap Planning (Department of Environment, Land, Water and Planning – DELWP, 2021)

[1] Statistical Areas as defined by the ABS : 1270.0.55.001 - Australian Statistical Geography Standard (ASGS): Volume 1 - Main Structure and Greater Capital City Statistical Areas, July 2016

Data Type	Location	Reference/ Comment
	NSW	NSW Environmental Planning Instrument (DPIE, 2008)
	QLD	Land Use in Queensland (Department of Environment and Science, 2019)
	NT	Land Use Mapping Project of the Northern Territory (Department of Environment, Parks and Water Security, 2017)
Microsoft Buildings	Australia wide	Bing Maps country wide building footprints in Australia - Open Street Maps (Microsoft, 2020)

2.3 Literature

There are numerous studies and investigations that have been undertaken across some of the high priority areas. These are referenced and discussed throughout this report. These have been sourced from publicly available sources. A list of references has been provided in Section 8 and in the relevant appendices.

3 Short-Listing Process

3.1 Introduction

The first part of the project was to narrow down the focus of the investigations to short-listed flood affected areas throughout Australia. To do this, several key steps were undertaken. These are described below.

3.2 Spatial Flood Impact Mapping

The first part of the prioritisation process used a spatial flood impact mapping process based on IAG's residential property damage information (refer Section 2.1). This was undertaken using a 'Heatmap' process using spatial data analysis software (QGIS). The SA1 spatial data was adopted for this purpose, as it provides a sufficient resolution to be able to narrow down and identify key areas.

Two key criteria were adopted for the assessment:

- Annual Average Damage (AAD) for residential properties – this provides an understanding of the economic impact of flooding in a particular area for residential properties. While it does not include commercial properties, it provides a generally understanding of the magnitude of potential damages and provides a useful comparative indicator between different locations.
- Number of addresses affected by a 1 in 20 AEP flood event. While AAD does provide a representation of the damages across a number of AEP events, the frequency of flooding is important, both from a risk perspective as well as the ability to potentially mitigate against the damages. Generally, mitigation can be (in some cases) easier to target for more frequent events than rare and infrequent events.

The heatmap process adopted sums up the criteria above within a set radius. In this case, a radius of 0.05 degrees was adopted, which corresponds to approximately 6 kilometres. Under this approach, all SA1 values within a 0.05 degree radius from a particular point are added up. This process creates a spatial representation of the density of AAD as well as the properties affected in the 1 in 20 AEP. Both criteria were normalised to a score out of 100.

The next step in the process was to create a combined spatial score, based on an equal weighting of each criteria. An example of this process on the NSW North Coast is shown on **Figure 3**.

The combined map was used to derive an initial list of priority areas. This list was complemented with additional areas, as described in **Section 3.3**. The final long list of priority areas is presented in **Section 3.4.**

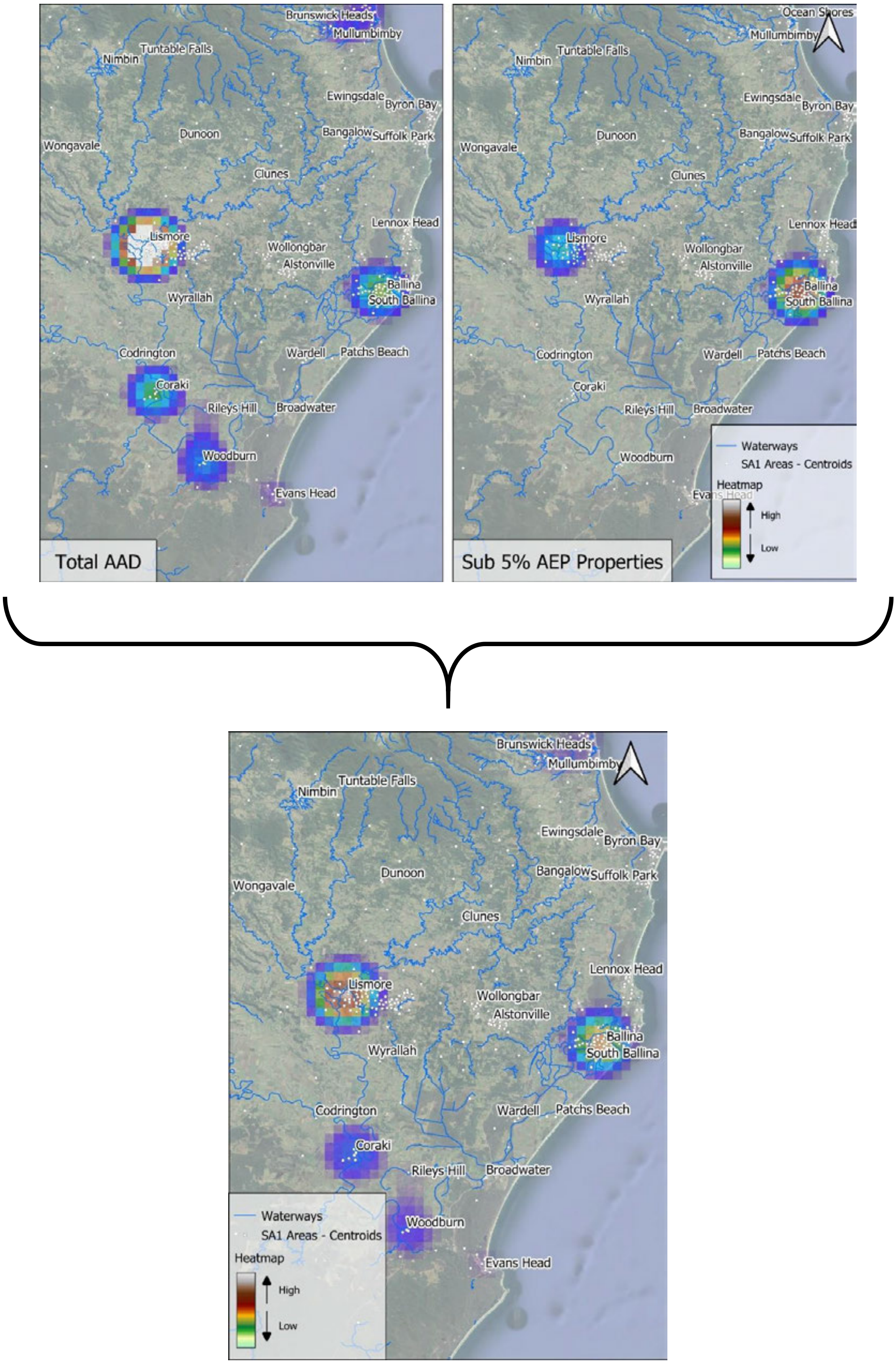

Figure 3. Combined Heatmap – NSW North Coast Example

3.3 Additional Areas Identified

The above process identified an initial list of priority areas. Further investigations were undertaken on the basis of the following:

- The large-scale nature of the prioritisation process may overlook specific, high localised damage areas across the country;
- In many locations, authoritative government-sourced hazard data either does not exist or has not been made available to insurers. This may lead to gaps or errors in IAG's view of flood risk which could lead to some flood affected areas being overlooked.

Two key cross checks were therefore undertaken to identify additional areas.

3.3.1 Areas with concentrated high damage values

As the heatmap analysis considers AAD within a radius around 6km, locations that had a high concentration of damage in a smaller area, may be overlooked. Therefore, a further cross check was undertaken by identifying SA1 areas with very high AAD.

3.3.2 Locations identified in the Mitigation and Policy-in-Force (ICA, 2019) Report

The Insurance Council Australia (ICA) has recently undertaken an analysis of national Policy-in-Force[2] Insurance data with the purpose of identifying locations and drivers of higher insurance premiums and recommending interventions. The outcomes of this analysis are presented in the Mitigation and Policy-in-Force (ICA, 2019) Report.

This report outlines a series of key locations with relatively high insurance premiums that could highly benefit from the implementation of targeted flood mitigation measures.

As the ICA report used a different source database for their assessment. Therefore, the initial priority areas list derived using the heatmap approach was compared against the locations identified in the ICA report. Even though there was significant overlap between the two lists, there were key locations mentioned in the ICA report that had not been contemplated in the initial heatmap list. These locations were reviewed and included were appropriate.

3.4 Long List

Based on the analysis described in **Section 3.2 and 3.3**, a long list of 49 areas were identified. These locations are identified in Table 2.

[2] Policy-in-Force (PIF) data is information that describes the actual purchasing of insurance products by policyholders at address level. According to ICA (2019), PIF 2019 comprises 12.9 million geocoded policy records for Australia, representing an estimated 96% of all policies currently in force. Policies include commercial, strata, home, contents, landlords, SME and ISR.

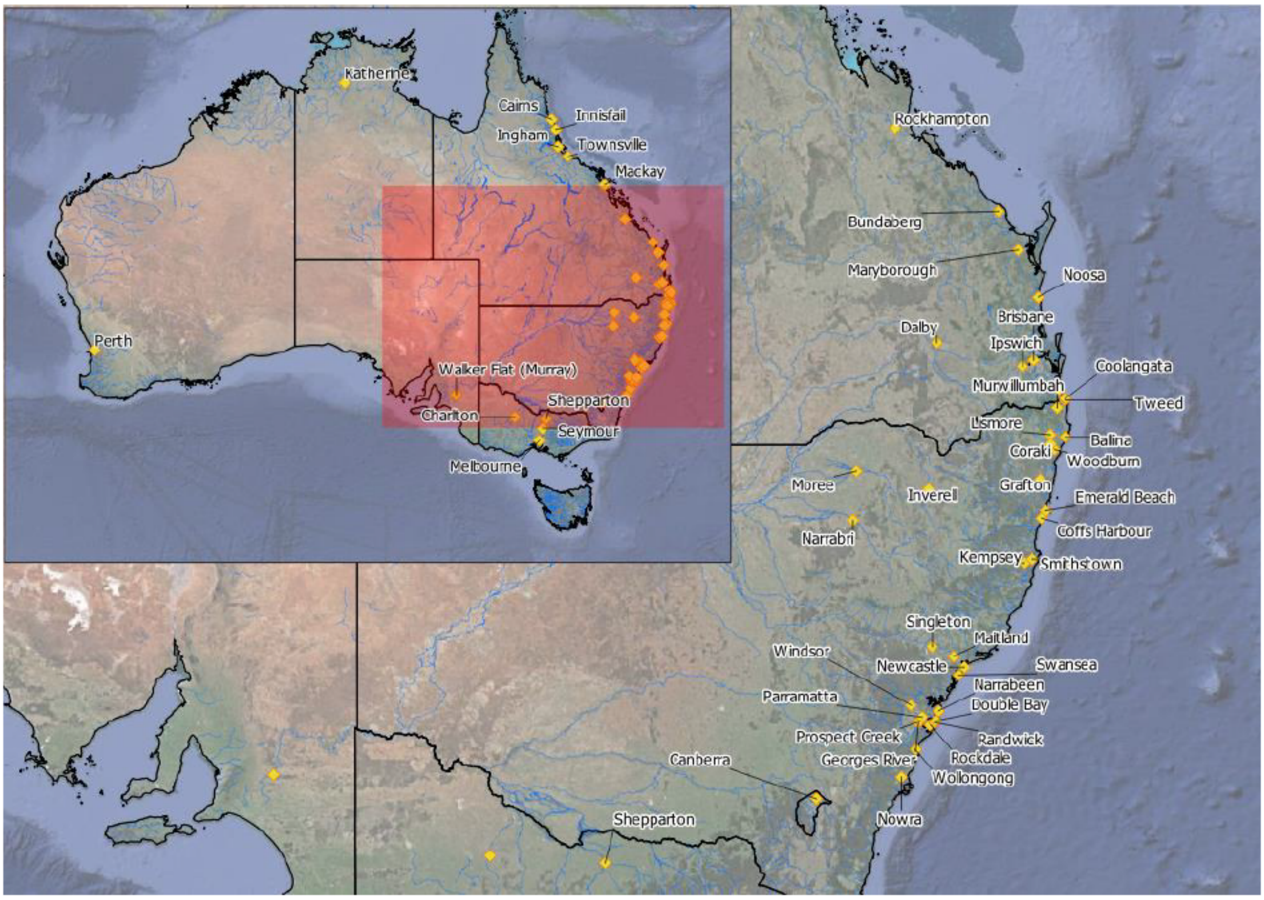

Figure 4. Long-List Locations

Table 2. Long-List Options

Name	State	Name	State	Name	State
Ballina	NSW	Inverell	NSW	Perth (Swan River, generally from Ascot to Caversham)	WA
Brisbane (Brisbane River)	QLD	Ipswich	QLD	Prospect Creek	NSW
Bundaberg	QLD	Katherine	NT	Randwick	NSW
Cairns	QLD	Kempsey	NSW	Rockdale	NSW
Canberra (largely around Sullivans Creek)	NSW	Lismore	NSW	Rockhampton	QLD
Charlton	VIC	Mackay	QLD	Shepparton	NSW
Coffs Harbour	NSW	Maitland	NSW	Singleton	NSW
Coolangatta	QLD	Maryborough	QLD	Smithtown	NSW
Coraki	NSW	Melbourne (largely around Yarra River and Maribyrnong River)	VIC	Swansea	NSW
Dalby	QLD	Moree	NSW	Townsville	QLD

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Name	State	Name	State	Name	State
Double Bay	NSW	Murwillumbah	NSW	Tweed	NSW
Emerald Beach	NSW	Narrabeen	NSW	Walker Flat (Murray)	SA
Georges River (Near Warwick Farm)	NSW	Narrabri	NSW	Windsor	NSW
Gold Coast	QLD	Newcastle	NSW	Wollongong (various catchments)	NSW
Grafton	NSW	Noosa	QLD	Woodburn	NSW
Ingham	QLD	Nowra	NSW		
Innisfail	QLD	Parramatta	NSW		

3.5 Multi-Criteria Analysis

A multi-criteria analysis (MCA) was adopted to assist in narrowing the long list and focusing the assessment on a few select areas. Three key categories were adopted:

- Flood Impact Assessment – a measure of the total flood impact for a particular area;
- Mitigation Feasibility – criteria intended to provide a broad indication of the potential viability of mitigation within a study area, based on a high level review by the project team;
- Socio-economic Criteria – a measure of the general socio-economic level within an area.

Following discussions with IAG, the socio-economic criteria was included to ensure that lower socio-economic areas would be included in the analysis. These are areas that may have lower affordability for mitigation measures, or where the community may have less ability to afford adequate insurance cover or a lesser ability to recover following a significant flood event.

The scores for each criteria were on a 1 (low) to 3 (high) basis. A summary of the criteria is provided in Table 3.

Table 3. Criteria used in the Assessment

Category (Weighting as a %)	Criteria	Description
Flood Impact Score (40%)	AAD	Total annual average damage identified within each of the long list locations.
	Population at Risk	Calculated on a weighted average annual number of addresses identified at risk of flooding.
Mitigation Feasibility Score (40%)	Scale of Works	A qualitative score, based on a review by the project team, on the general scale of the works required to achieve mitigation in the areas.
	Concentration of Damages	A qualitative score - represents the concentration of damages within areas of the priority area. Higher concentrations of damages can be easier to mitigate against, as the mitigation measure can focus on a more localised area.

Category (Weighting as a %)	Criteria	Description
	Constraints	A qualitative score representing the likely constraints to potential mitigation as assessed by the project team. This may include density of development (limiting potential mitigation) or the overall flood depths and scale of flooding etc.
Socio-economic criteria (20%)	Gross Regional Product (GRP)	A score based on the GRP for the Local Government Area (LGA). Higher GRP results in a lower score.
	SEIFA	ABS criteria which is a measure of socio-economic welfare.

3.6 Short-Listed Areas

Following the MCA (Section 3.5), the higher ranked areas were reviewed in conjunction with the project team and IAG stakeholders. The short-listed study areas were then selected on the basis of the MCA and the following additional criteria:

- Ensuring an appropriate geographical spread of study areas, with a range of flood behaviours and conditions. For example, if two study areas were adjacent to each other, then only one would be adopted;
- Ongoing works or funding applications. For example, Bundaberg is understood to be well progressed towards undertaking works and investigations at present and has therefore not been short-listed for further investigation
- Excluded catchments where effective flood mitigation would likely require in excess of $150M of investment and would require a significant timeframe for planning (these include Brisbane River, Melbourne, Perth, Parramatta and Windsor (in the Hawkesbury-Nepean floodplain)).

Of the selected study areas, Woodburn, Coraki and Smithtown are relatively small townships with a number of constraints. These areas were identified for testing of potential property level mitigation measures (Section 5). To provide a range of case study areas, Narrabeen, Wollongong and Noosaville (in Noosa) were also adopted for the property level mitigation.

Dalby was also included. The IAG database in this area is not well represented. However, a literature review of the locations identified significant flooding issues and was therefore included.

Following this short list process, an additional study area was included – Seymour in Victoria. While Seymour is relatively small, it had undertaken investigations into a potential flood levee in recent years, but this did not proceed due to funding issues. Seymour was included in this project as a test case for smaller study areas.

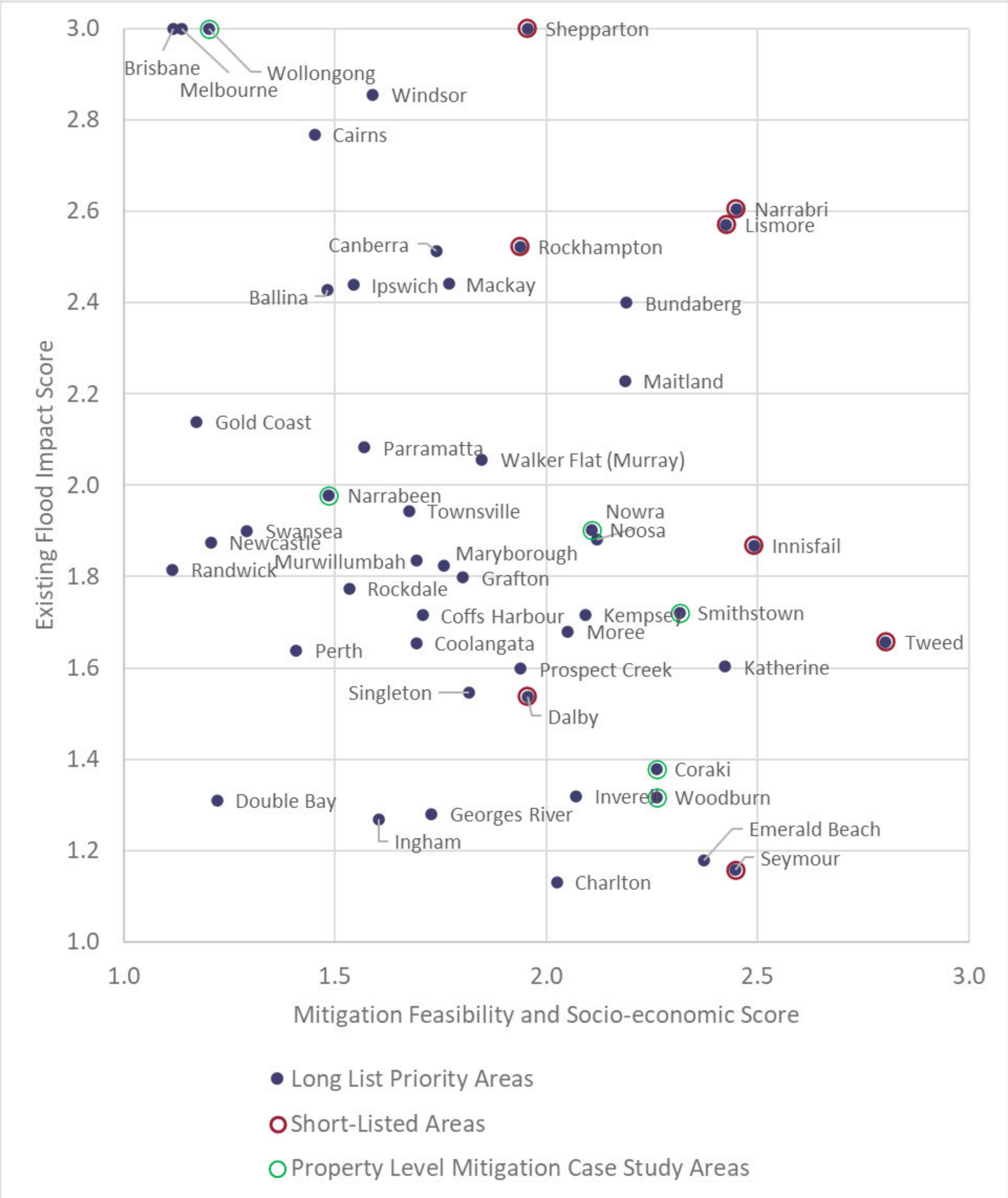

Figure 5. MCA Summary

4 Short-Listed Areas

A strategic level review was undertaken of the short-listed areas (Figure 6). The intention of this review was to:

- Provide an understanding of the existing flood risks, based on available literature and information for the area;
- Identify potential structural flood mitigation measures that may be possible for the area;
- Undertake a strategic level economic viability assessment on these mitigation measures. The economic assessment has been undertaken based on the key assumptions and methodology identified in Appendix A.

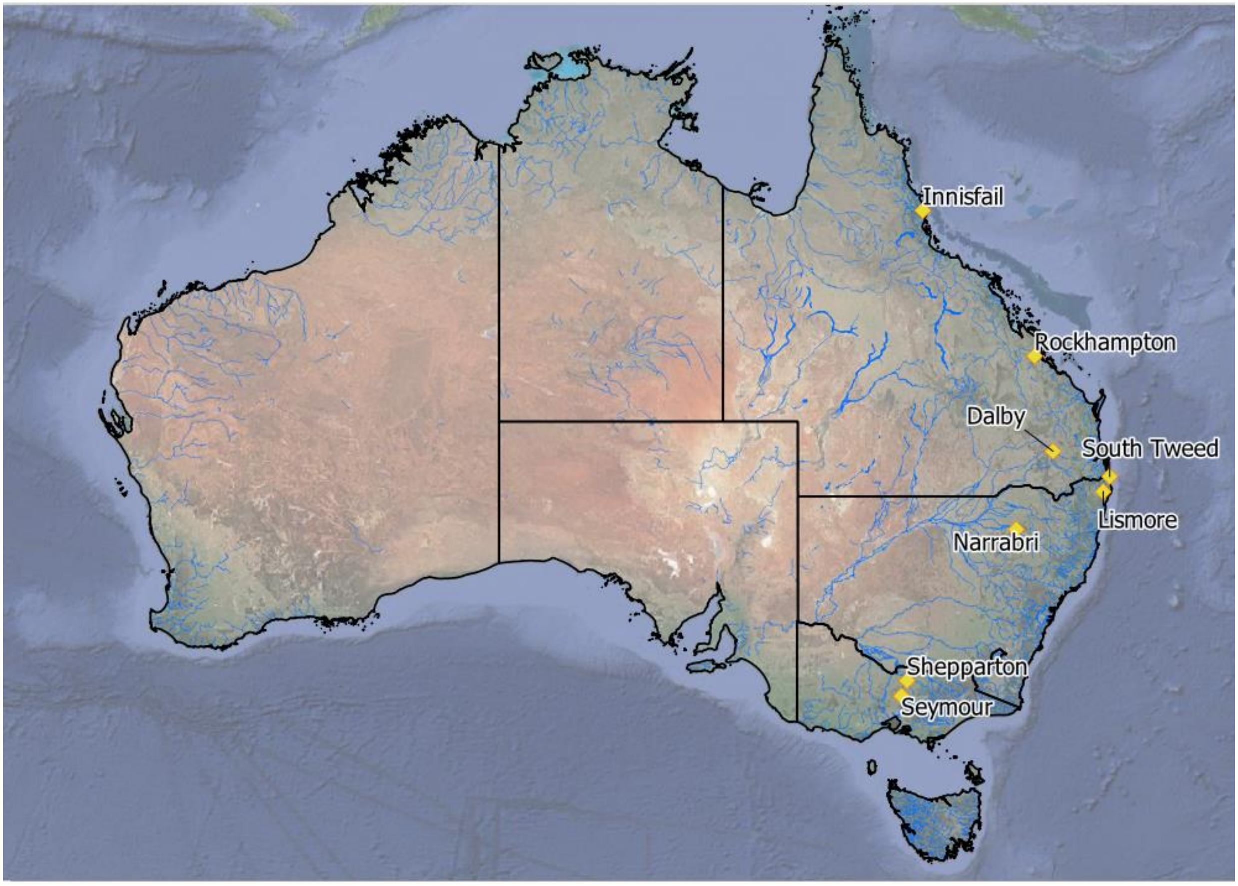

Figure 6. Short-Listed Locations

Potential mitigation measures have been based on available reports within each of the short-listed areas, together with a review of the flood behaviour and key constraints. Some cross checking of flood behaviour and identified options has also been undertaken with a selection of stakeholders for some of the short-listed areas.

It is essential to note that unless previous assessment of the options has been undertaken, further analysis and design will be required to understand the mitigation performance and potential impacts that the mitigation may have on flood behaviour and properties. Community acceptance as well as environmental and heritage impacts will also be required to be investigated. Additionally, the cost estimates presented here should be refined based on more detailed information.

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Further details on each of the short-listed areas is provided in **Appendix A**.

Table 4 provides a summary of flood mitigation measures identified across all of the short-listed study areas.

Table 4. Summary of Flood Mitigation Measures

Floodplain	Item	Description
Lismore	As noted, the analysis in this report was completed in August 2021, prior to the flooding in the NSW Northern Rivers region in early 2022. We acknowledge that there is ongoing work being undertaken by Lismore City Council, CSIRO, the Northern Rivers Reconstruction Corporation, NSW and Federal Governments and the National Recovery Resilience Agency to mitigate against flood risk and build community resilience in Lismore. Given this ongoing work, analysis on potential mitigation measures has not been undertaken on Lismore.	
Shepparton	Level of Design	Strategic. While the mitigation was assessed in 2002 (with a higher protection), no update to this assessment has been undertaken
	Flood Mitigation Performance	Targeting a 1 in 50 AEP protection for those areas protected by the levees. May be required to lower this protection if negative flood impacts.
	Cost Estimate	**$47.7M ($40M - $50M)** Strategic only.
	Constraints	• Potential environmental constraints, particularly for the floodway • Uncertain on community acceptance of the scheme.
	Further Work Required	A flood risk management study (as per Section 1.4), to undertake appropriate optioneering and community engagement.
Narrabri	Level of Design	Strategic. No formal modelling or investigation of mitigation options undertaken.
	Flood Mitigation Performance	Targeting a 1 in 10 to 1 in 20 AEP protection for a number of areas in Narrabri. Potential for flood impacts on adjacent properties – modelling required to refine scheme.
	Cost Estimate	**$59.1M ($55M-$65M)**
	Constraints	• Potential flood afflux • Several road crossings and interfaces with private properties • Environmental considerations are uncertain
	Further Work Required	Floodplain risk management study and plan to be completed (currently in progress), including appropriate optioneering and community engagement.
Innisfail	Level of Design	Strategic. While the mitigation was assessed in 2014 (with a higher protection), no update to this assessment has been undertaken.
	Flood Mitigation Performance	Targeting a 1 in 50 AEP protection for those areas protected by the levees. May be required to lower this protection if negative flood impacts are identified.
	Cost Estimate	**$52.7M ($50M-$60M)**
	Constraints	• Potential environmental constraints, particularly for the dredging

Floodplain	Item	Description
		• Challenges with some levees crossing creeks and roads. Flood gates required • Uncertain on community acceptance of the scheme • Potential flood afflux of the scheme, further investigation required.
	Further Work Required	A flood risk management study (as per Section 1.4), to undertake appropriate optioneering and community engagement.
Rockhampton	Level of Design	Detailed design, ready for tender (pending funding).
	Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levees.
	Cost Estimate	**$80.4M (detailed estimate)**
	Constraints	• Relatively low, given EAR undertaken.
	Further Work Required	Minimal, ready to be tendered.
South Tweed	Level of Design	Strategic.
	Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levee.
	Cost Estimate	**$30.9M ($25M-$35M)**
	Constraints	• Potential environmental constraints, particularly for Phillip Parade extension • May be further engineering constraints, particularly for the Phillip Parade extension.
	Further Work Required	A flood risk management study (as per Section 1.4) has been undertaken. Further investigation and optioneering required on the levee options.
Dalby	Level of Design	Strategic. Further analysis required to understand relative benefits of proposed options
	Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levee, uncertain for the flowpath.
	Cost Estimate	**$107M ($100M-$110M)**
	Constraints	• Potential environmental constraints, particularly for the excavation • Land acquisition issues along the flowpath. • Uncertain on community acceptance of the scheme • Potential flood afflux of the scheme, further investigation required.
	Further Work Required	A flood risk management study (as per Section 1.4), to undertake appropriate optioneering and community engagement.
Seymour	Level of Design	Detailed
	Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levee.
	Cost Estimate	**$25M** Detailed
	Constraints	Potential community objection, although it is understood that this primarily was associated with the funding rather than the levee itself.
	Further Work Required	Finalise detailed design

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5 Economic Assessment

5.1 Overview

A preliminary economic assessment was undertaken on the strategic level mitigation measures that were identified for each of the short-listed areas in Section 4. The economic assessment methodology and key assumptions are discussed in **Appendix B**.

5.2 Scenarios for Assessment

For each of the short-listed areas, two scenarios have been assessed:

- A base or existing case, representative of existing flood behaviour and conditions;
- Flood mitigation scenario, representative of the study areas post-implementation of the different mitigation measures identified in Section 4.

The scenarios incorporate an estimate of the influences of climate change over the economic assessment period, as discussed in **Appendix B.**

5.3 Base Case Damages

A summary of the total base case Annual Average Damages (AAD) is provided in Figure 7, with the relative proportions, or contributions to AAD, shown in Figure 8 for each of the study areas. The base case AAD ranges across the areas considered from approximately $5 - $85M. These values are shown in Table 6.

As noted in **Appendix A**, there is a potential range that could be considered for the intangible portion of flood damage costs. While the low range has been adopted for this assessment, Figure 9 and Table 5 provides an understanding of the potential variability in the intangibles depending on the underlying assumptions that are made.

For Dalby, as noted in Section 3, limitations in the IAG flood database required an alternative source of AAD estimates to be adopted. Therefore, the previous study, as identified in **Appendix A**, was used to estimate the flood damages. There may be some differences in the underlying assumptions between that study and the methodology adopted for this report.

The overall damages are derived based on the IAG residential damages that were made available to Rhelm for the purposes of this project. The overall analysis is therefore reliant on the underlying accuracy of this dataset.

Table 5. Existing Intangible Flood Damage Estimate – Ranges ($M)[3]

Component	Lismore	Shepparton	Narrabri	Innisfail	Rockhampton	South Tweed	Dalby	Seymour
Low Range	**$6.2**	**$10.0**	**$3.7**	**$3.3**	**$3.1**	**$1.9**	**$2.5**	**$0.4**
Medium Range	$11.2	$20.1	$7.7	$5.5	$4.5	$6.8	$5.1	$0.6
High Range	$58.0	$29.9	$30.1	$22.0	$17.7	$11.3	$7.1	$3.1

[3] The low range has been adopted for the economic assessment.

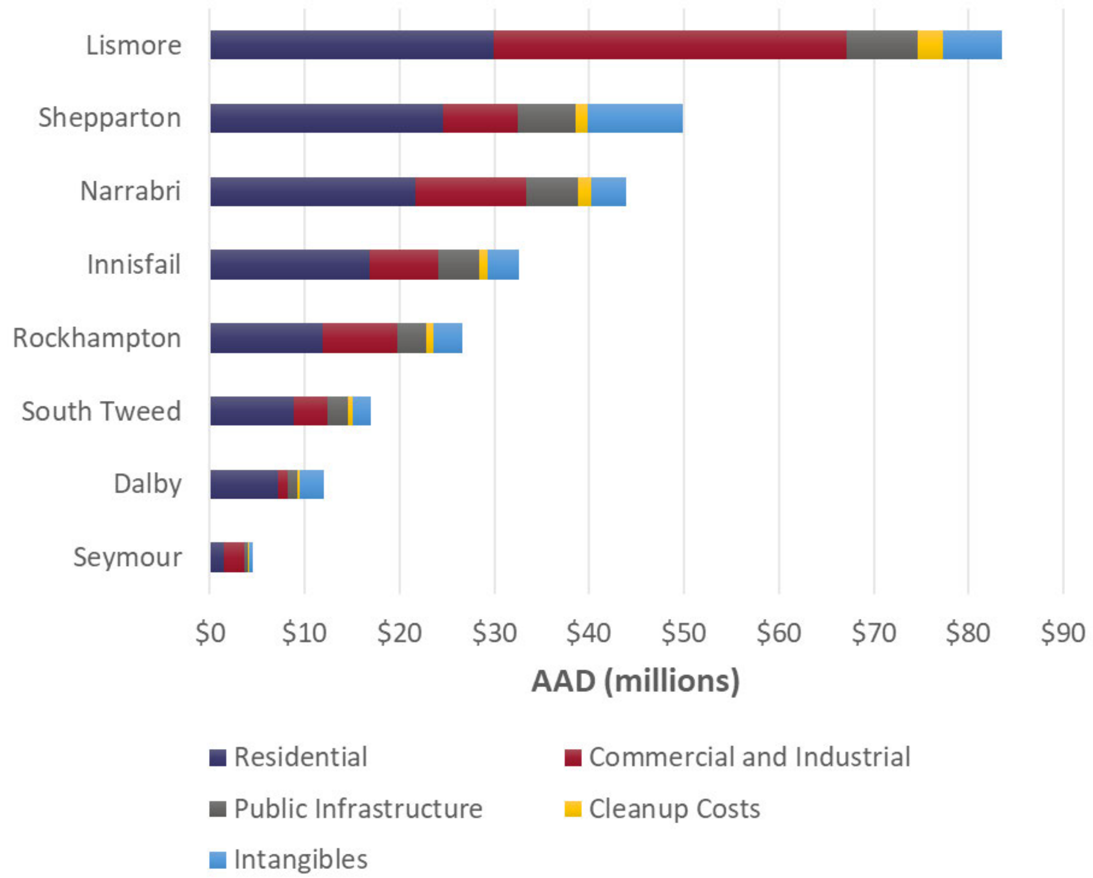

Figure 7. Total Annual Average Damage (AAD) Cost by Flood Affected Area - Base Case Scenario

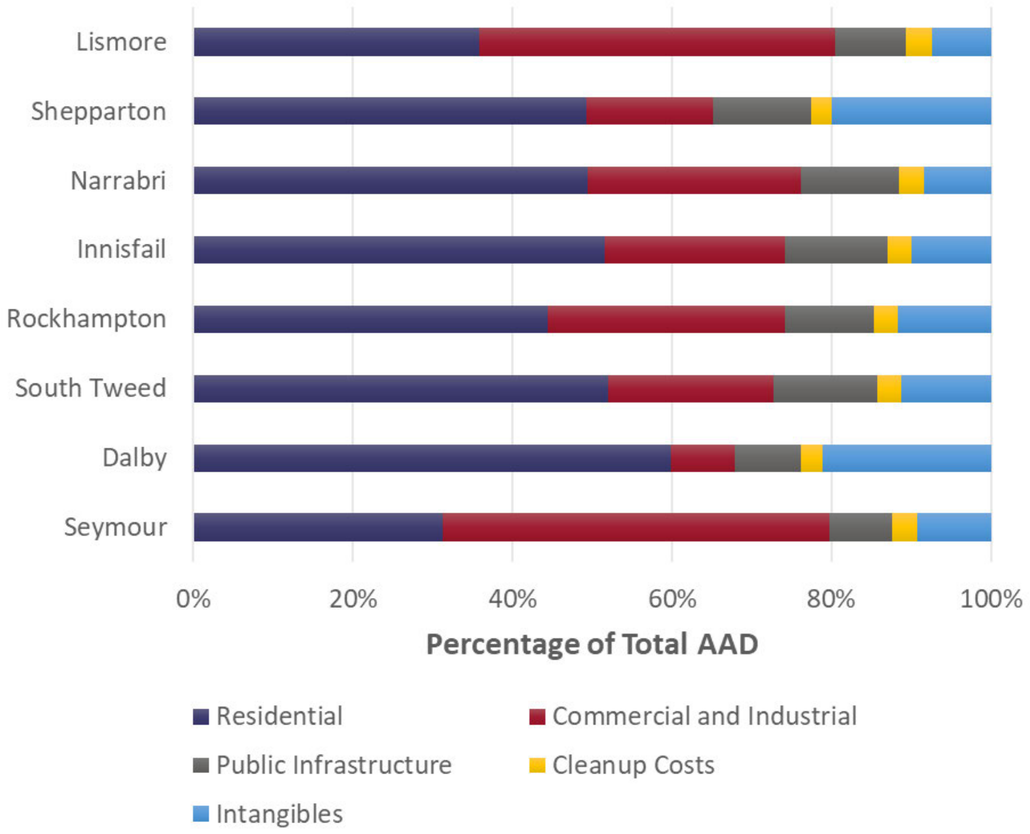

Figure 8. Contribution to Total AAD - Base Case Scenario

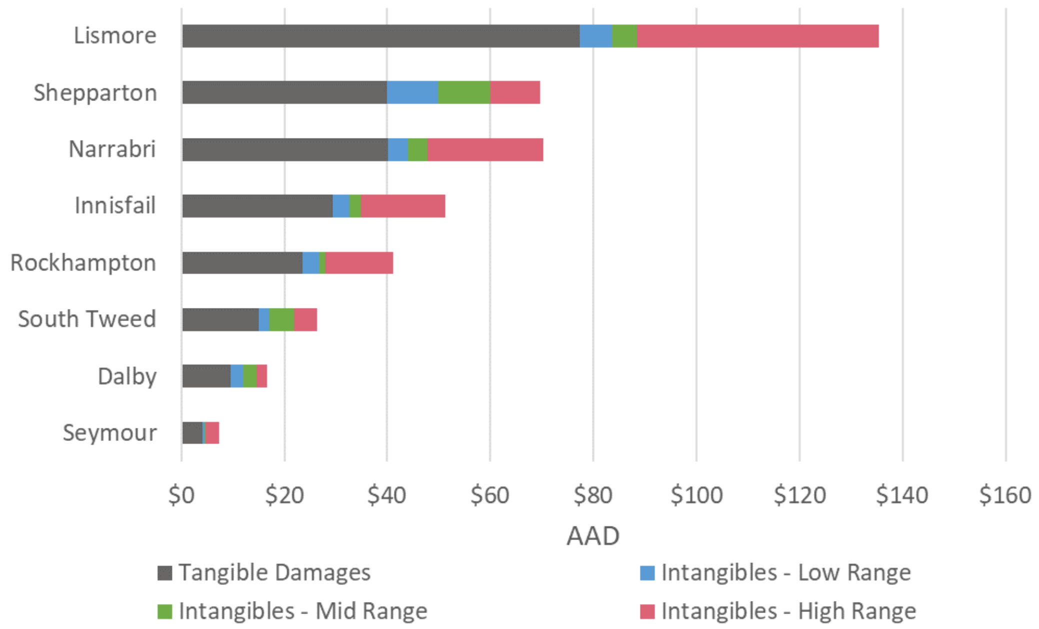

Figure 9. Intangible Flood Damage - Indicative Ranges and Total AAD - Base Case Scenario[4]

[4] The low range has been adopted for this assessment

5.4 Mitigation – Reduction in Damages

In order to estimate the effectiveness of the different mitigation measures, a preliminary review of the likely protected properties was undertaken. This identified key areas that would likely be protected, and the level of protection that would be provided (e.g. 1 in 20 AEP). This information was provided to IAG, who then recalculated the residential damages data, as per Section 2.1, with the protection in place. The information provided by IAG was for the existing climate scenario (CC0), and it was assumed that the increase in damages would occur on a similar proportion to the base case scenario.

Using this information, the AAD under the mitigation scenario was estimated. A summary of this is provided in Figure 10.

In addition to the reduction in AAD under each of the mitigation options, there are also a number of residential properties which are no longer inundated under different events. A summary of the number of residential properties flooded under the base case and the mitigation scenario are summarised in Figure 11, for a range of design flood events.

For some areas, there is no change to the number of properties affected in the 1 in 100 AEP flood, as the levee only protects up to a smaller AEP flood. However, there is a reasonable decrease in affected residential properties in the 1 in 20 AEP. For other areas, like Rockhampton, there is an overall reduction in properties affected in the 1 in 100 AEP flood, as the mitigation works are designed for this event. However, as the mitigation works only target a part of the floodplain, there are a number of additional properties remaining within the 1 in 100 AEP extent.

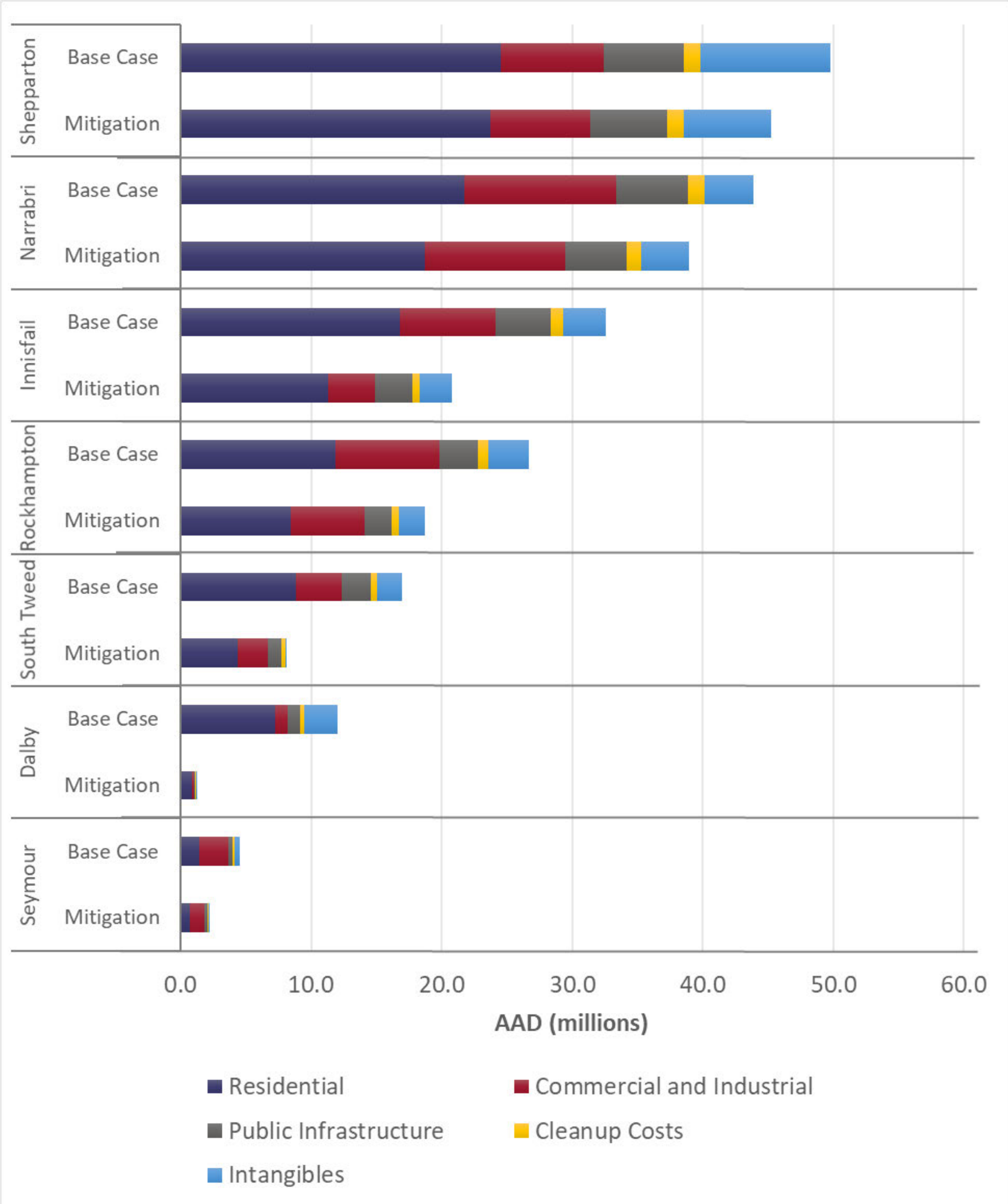

Figure 10. Comparison of Annual Average Damages - Base Case and Mitigation Scenario

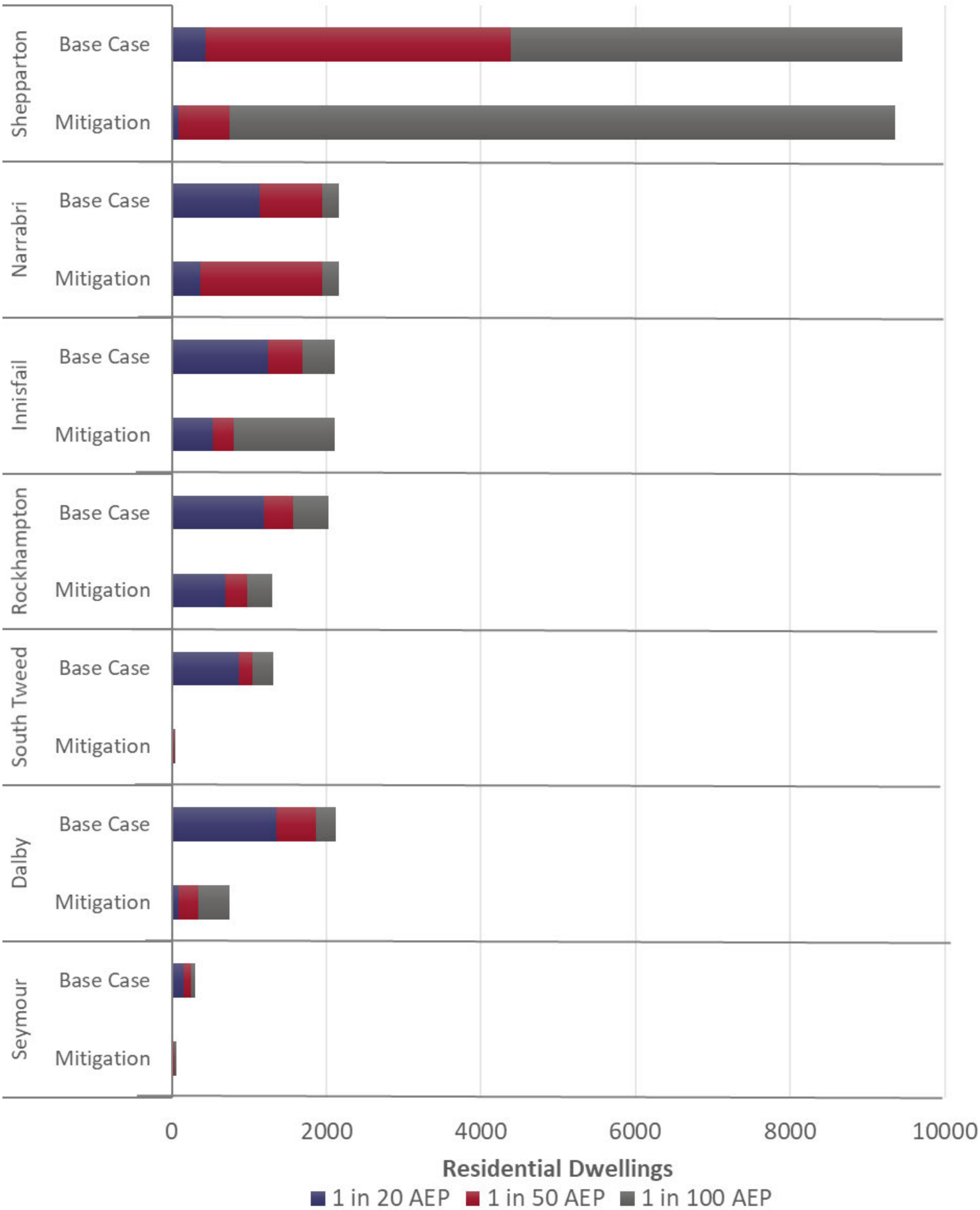

Figure 11. Number of Residential Properties Protected by Mitigation[5]

[5] Residential dwellings affected are those residential properties where there is overground flooding on the property, not necessarily overfloor flooding.

Table 6. Summary of Annual Average Damages ($M)

Component	Shepparton		Narrabri		Innisfail		Rockhampton	
	Base Case	Mitigation	Base Case	Mitigation	Base Case	Mitigation	Base Case	Mitigation
Residential	24.6	23.7	21.7	18.7	16.8	11.3	11.9	8.5
Commercial & Industrial	7.9	7.6	11.7	10.8	7.3	3.6	7.9	5.6
Public Infrastructure	6.1	5.9	5.4	4.7	4.2	2.8	3.0	2.1
Cleanup Costs	1.3	1.3	1.3	1.2	1.0	0.6	0.8	0.6
Intangibles	10.0	6.7	3.7	3.7	3.3	2.4	3.1	1.9
Total	**49.8**	**45.2**	**43.9**	**39.0**	**32.6**	**20.8**	**26.7**	**18.7**
	South Tweed		Dalby		Seymour			
	Base Case	Mitigation	Base Case	Mitigation	Base Case	Mitigation		
Residential	8.8	4.4	7.2	0.9	1.4	0.7		
Commercial & Industrial	3.5	2.3	1.0	0.1	2.2	1.2		
Public Infrastructure	2.2	1.1	1.0	0.1	0.4	0.2		
Cleanup Costs	0.5	0.3	0.3	0.0	0.1	0.1		
Intangibles	1.9	0.1	2.5	0.0	0.4	0.1		
Total	**17.0**	**8.1**	**12.0**	**1.2**	**4.6**	**2.2**		

5.5 Cost Benefit Analysis

The results of the cost benefit analysis are summarised in Figure 12, Figure 13 and Table 7. Benefit cost ratio (BCR) values in excess of 1 are where the present value of the benefits exceed the costs, and therefore the option would be considered economically viable.

The BCR for the mitigation works are in excess of 1 (Figure 13), and therefore would be considered to be economically viable.

For Dalby, there is some uncertainty on the overall cost of the southern floodway option in particular. Given the scale of this project, further work would be required to refine that estimate. There is also a lower cost, smaller scale floodway that may be a consideration (refer **Appendix A**). Finally, the Dalby mitigation also includes a levee. The levee on its own may assist in diverting water way from the township and may be worthwhile investigating as a stand-alone option.

Figure 12. Comparison of Costs and Benefits

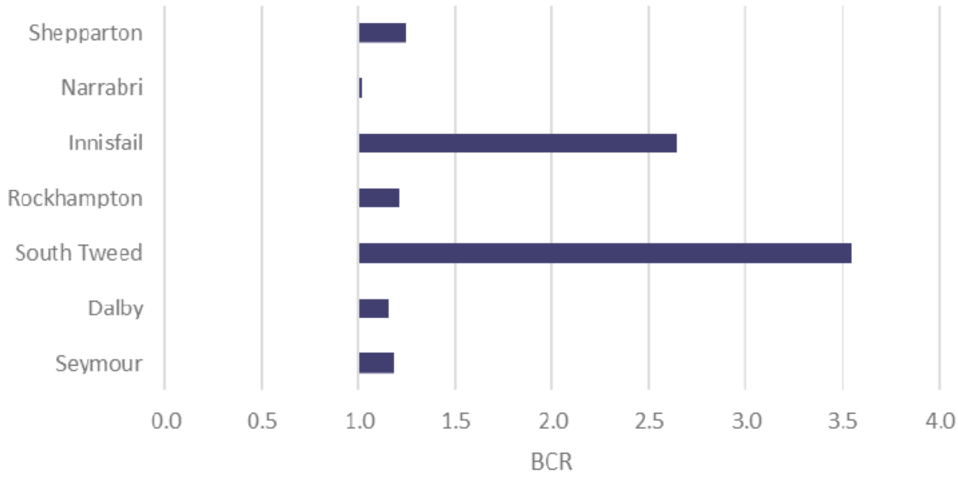

Figure 13. Benefit Cost Ratio for Mitigation Works

Table 7. Economic Results – Summary

Location	Present Value Costs ($M)	Present Value Benefits ($M)	BCR	Net Present Value ($M)
Shepparton	$45	$56	1.2	$11
Narrabri	$55	$57	1.0	$1
Innisfail	$49	$130	2.6	$81
Rockhampton	$75	$91	1.2	$16
South Tweed	$29	$103	3.5	$74
Dalby	$100	$116	1.2	$16
Seymour	$23	$28	1.2	$4

5.6 Sensitivity Analysis

A sensitivity analysis was undertaken for Seymour, to understand the relative robustness of the assessment. These results are summarised in Table 8. They suggest that for large increases in the cost estimate or reductions in the benefits may reduce the BCR below 1.

As noted in **Appendix B**, climate change is incorporated within the economic analysis. A sensitivity analysis was undertaken by removing climate change from the analysis (and assuming the flood damages do not change over time). The results of this are summarised in Table 8. This shows only a relatively minor impact on the BCR.

Table 8. Sensitivity Analysis – BCR Results

Sensitivity Scenario	Seymour
3% Discount Rate	2.0
7% Discount Rate (Adopted BCR)	**1.2**
10% Discount Rate	0.9
Cost Estimate +40%	0.8
Cost Estimate +20%	1.0
Cost Estimate –20%	1.5
PV Benefits +20%	1.4
PV Benefits –20%	0.9
PV Benefits –40%	0.7
Climate Change	1.1

6 Property Level Mitigation

6.1 Introduction

As identified in Section 1.4, flood risk management includes the consideration of not just structural flood modification options, but also wider consideration of emergency management and property level mitigation. As part of this overall project, a review was undertaken on a sub-set of the property level mitigation alternatives, namely:

- Flood resilience;
- House raising;
- Land swap.

The focus of this assessment is on existing dwellings, and the modification of those existing dwellings on the basis of the above (with the exception of the house relocation). The purpose of the assessment is to determine the economic viability of these options.

6.2 Representative Areas

To support the analysis, six representative areas were chosen to undertake testing of the various alternatives. These areas were high ranked locations from the short-listing process in Section 3, and include:

- Coraki (Figure 14);
- Woodburn (Figure 14);
- Smithtown (Figure 15);
- Noosaville;
- Narrabeen; and,
- Wollongong.

Each of these locations have a range of different types of flood behaviour and types of development. Coraki, Woodbury and Smithtown are all small townships on large river systems and have relatively frequent and deep flooding. The Narrabeen suburb is primarily affected by flooding from Narrabeen Lagoon, which tends to be of relatively long duration. Wollongong, by comparison, is more flash flooding generated by the Illawarra Escarpment.

For each of the areas, IAG provided information for every address within the suburb. A representative property with a floor level of 0.4 metres above ground was adopted for the base case. Based on this information, average damages were extracted for all addresses across a range of floor levels. In addition to the information from IAG, intangibles (excluding risk to life) were also added to the values provided based on **Appendix A**.

The estimates of damages are summarised in Figure 16. In this figure, values for the "<=10", for example, are the average AAD for all properties where overfloor flooding occurs in events up to and including the 1 in 10 AEP. It provides an understanding of the average damages for different floor levels. However, it is limited by the number of properties within each category. The proportion breakdown is provided in Figure 17 shows that some locations, such as Smithtown, have the majority of the properties in the 1 in 10 AEP or less category. This can lead to some skew in the averages that are calculated for each area.

Rather than looking at the individual areas, Figure 18 provides a summary of AAD across all areas.

It is noted that a representative house was applied for the purposes of this analysis. In reality, many of these areas have dwellings that are set higher than 0.4 metres and some would have dwellings set at near ground level and therefore the damage profile would look different.

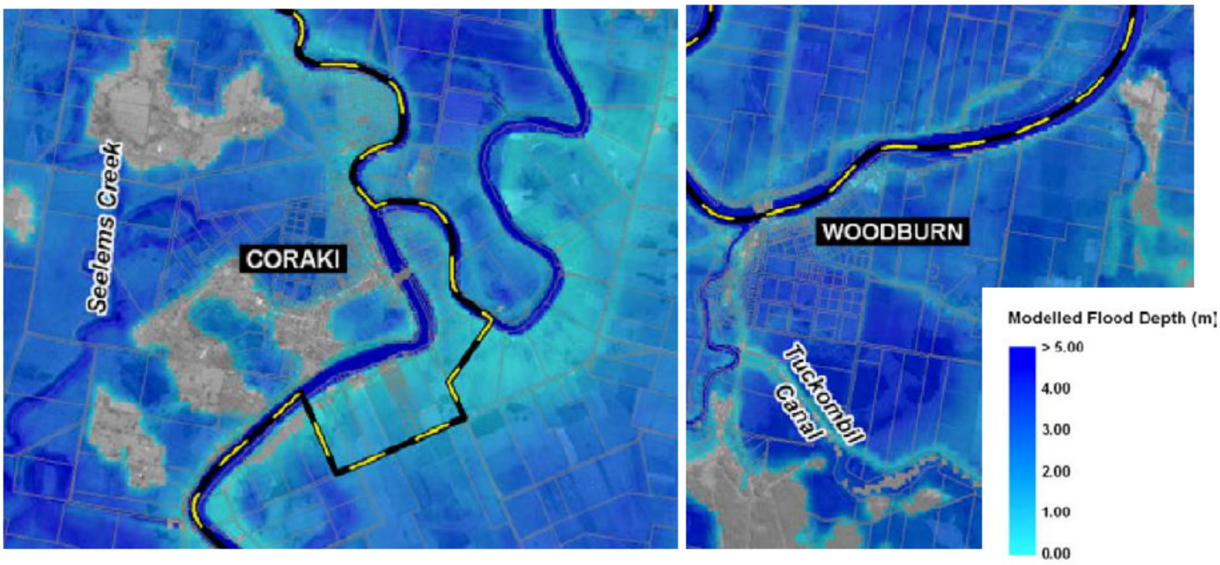

Figure 14. 1 in 100 AEP Flood Depths – Coraki and Woodburn (BMT WBM, 2011)

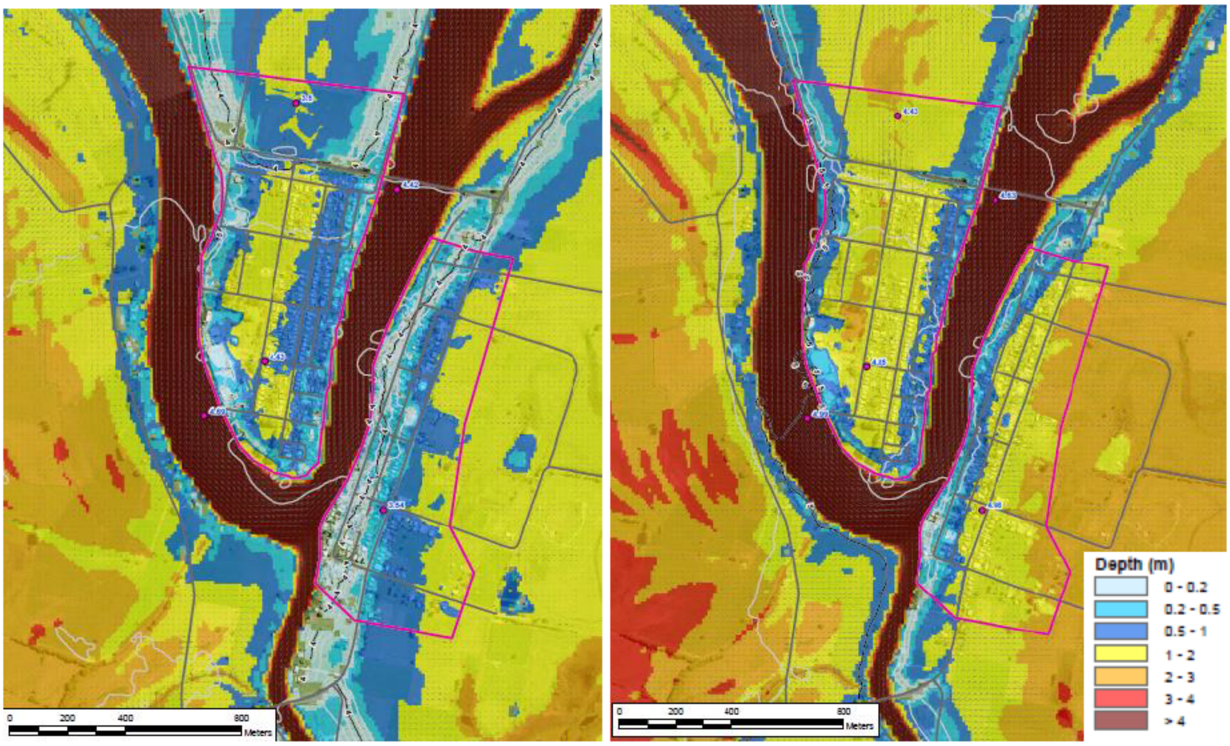

Figure 15. Flood Depths in the Smithtown Area – left 1 in 20 AEP, right 1 in 100 AEP (Jacobs, 2019)

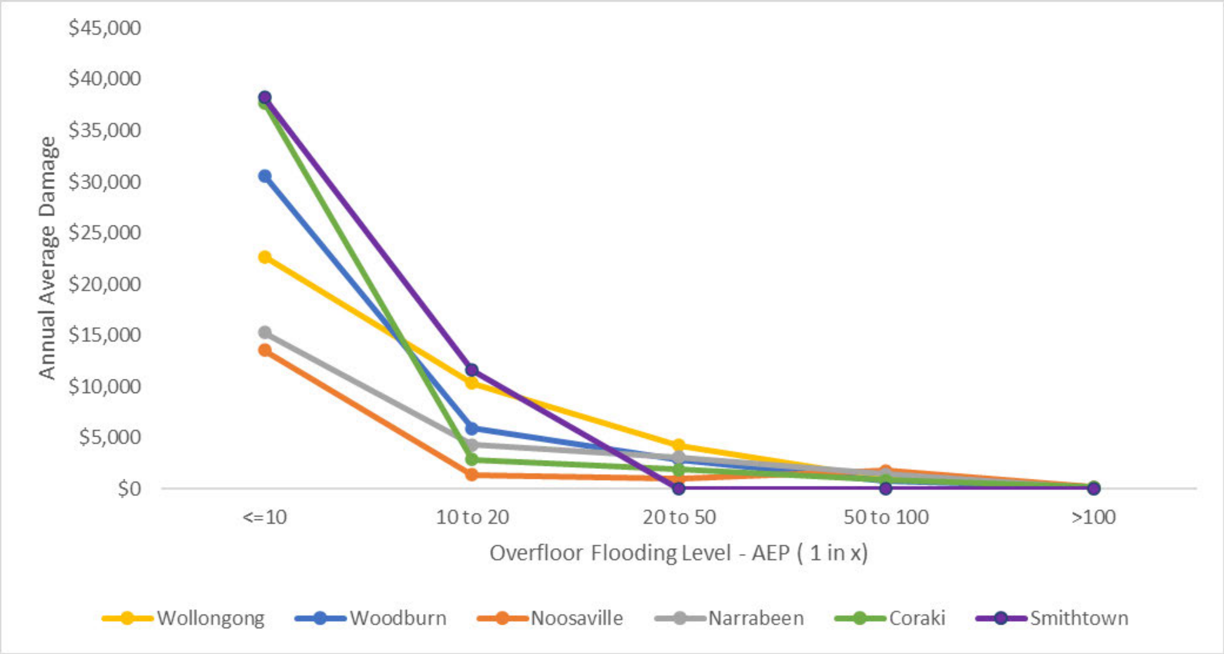

Figure 16. Mean Annual Average Damages for Properties for Representative Areas

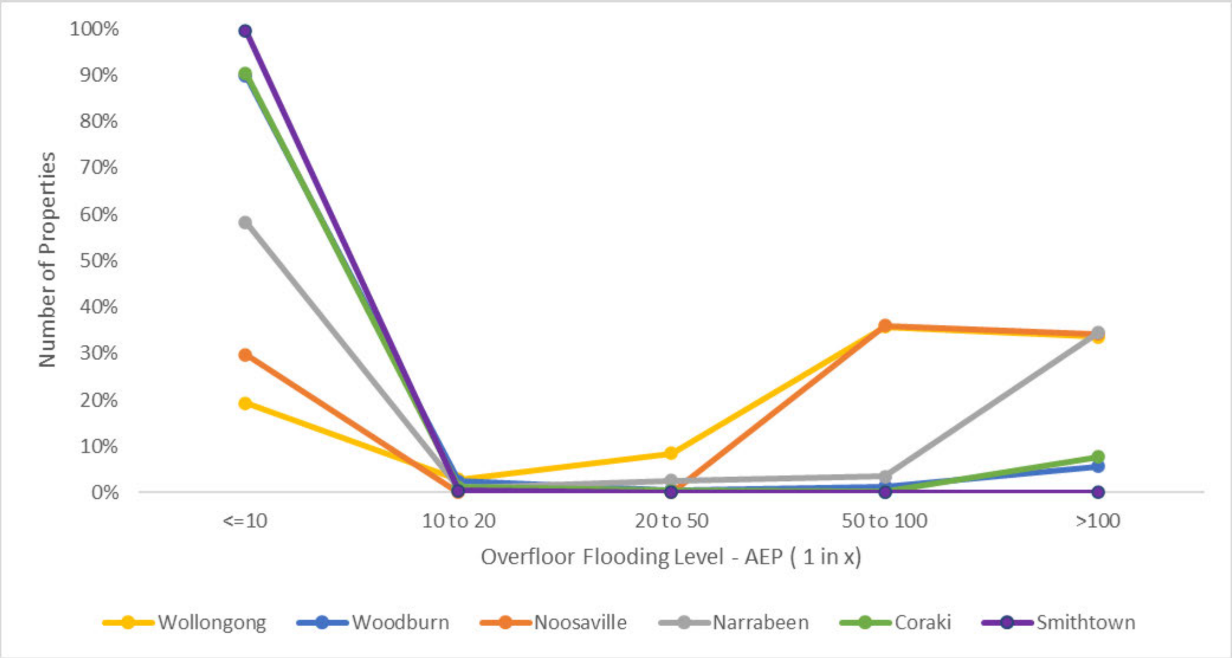

Figure 17. Proportion of Properties for Representative Areas

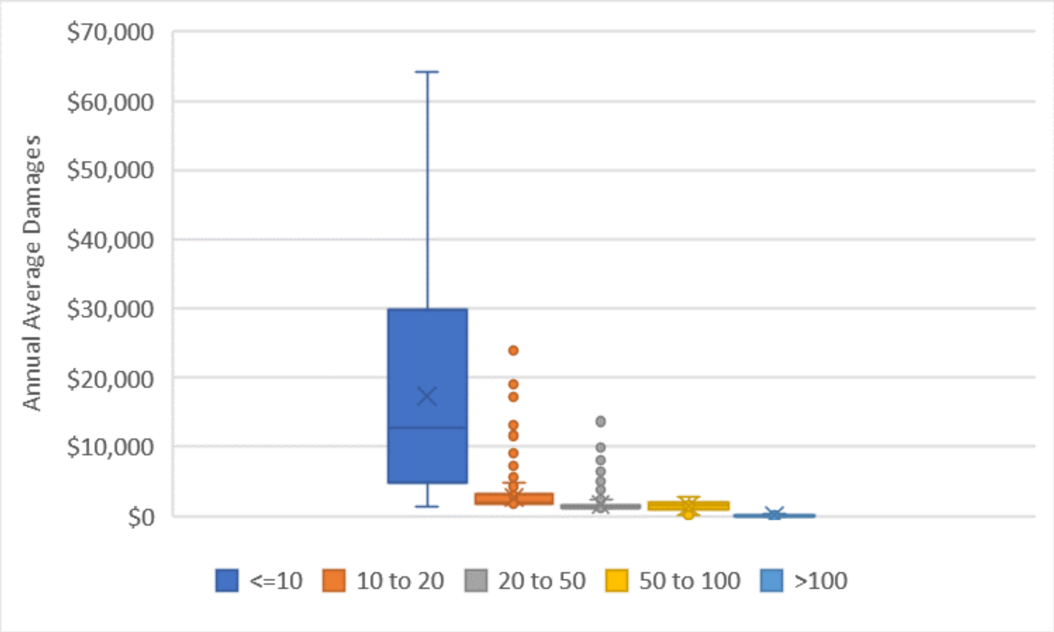

Figure 18. Range in Annual Average Damages for Properties for Various Design Events for All Representative Areas

6.3 Flood Resilient Building Measures

6.3.1 Overview

Flood resilient building measures include a range of potential materials and construction techniques that can be applied to either new buildings or retrofit to existing buildings. The focus of this report is on the latter. The following provides a brief overview on the literature and guidance available on flood resilient buildings and what might be considered as a part of the resilient measures. This is not an exhaustive review, but is intended to provide some background to the economic assessment.

With respect to the different components of residential flood damage, flood resilient building features focus on effort to minimise the direct building damages[6], being protecting elements of the building such as walls or floorings. It does not provide any benefit for the external damages (e.g. fences etc), contents damages or any significant reduction in intangible damages.

There are several guidelines and references for flood resilient buildings, both nationally and internationally. The two key references for Australia are the Blue Book (HNFMSC, 2006), developed for the Hawkesbury-Nepean floodplain but applicable to NSW and wider, and the more recent Queensland flood resilient guide (QRA, 2019). Despite its age, the blue book, *Reducing Vulnerability of Buildings to Flood Damage – Guidance on building in flood prone areas* (HNFMSC, 2006), represents a milestone in the field of flood-resistant building design. The majority of contemporary standards and reviews (including guidelines overseas) reference this document. A more detailed review of the Blue Book and international guidance is provided in Collier et al (2021). In addition, Collier et al (2021) presents draft

[6] In the literature on flood damages, building damages can sometimes be referred to as structural damages. To differentiate structural elements of a building (such as the frame) from non-structural elements (such as insulation), they have been referred to as building damages in this report.

resilient development and building controls for new residential development in the Hawkesbury-Nepean floodplain.

The focus of Collier et al (2021) and the Blue Book are primarily on new build construction, rather than retrofitting. However, QRA (2019) does include retrofitting measures.

Collier et al (2021) discussed what was referred to as "structural" resilience and "full" resilience. The former focused more on resilient measures that ensured minimal damage to the actual building structure. This included components such as steel frames (rather than timber frames which can warp and joints that separate) and wall vents to equalise differential water pressures on walls. Full resilience then looked at other measures such as insulation, flooring etc (i.e. protection to building damages).

Structural resilience is difficult to retrofit within an existing building. QRA (2019) suggests waterproofing the building frame as one way to achieve some resilience, but this may prove to be difficult to achieve in reality, due to access and the extensive amount of work required to gain access to the timber frame.

Drawing on the previous work undertaken by QRA (2019) and Collier et al (2021), the following are some examples of potential retrofitting resilient measures:

- Flooring – typically replacing carpet with tiles. This would be best suited to slab on ground type constructions. However, there can still be issues with tiles when there is contaminated floodwater. In the case where there is a timber floor, then it may just be left with the timber (say as polished boards where possible) (to ensure that the floor can be dried out). The other option would be to replace the timber floor with a product such as ModWood (a composite product made to look like timber that is used for decking, noting that it is not currently intended for interior usage).
- Walling – inclusion of fibre cement (rather than the typical fibreboard) sheeting on the walls and polystyrene insulation (rather than typical insulation like Glasswooll). In addition, vents are usually required to allow the walls to dry out after the flood and prevent mould. Note that there can still remain some questions on this, particularly on the ability to adequately dry the walls particularly on a retrofit and ensure that mould does not become an issue (or mud/ silt in the walls). It should be noted that there is no known fibre cement sheeting product in the market that has been tested to a common standard for flood inundation.
- Doors – solid core rather than hollow core. Again, this is identified in QRA (2019) but it is not certain as to how a solid core door would perform under prolonged duration.
- Custom kitchens. QRA (2019) discusses custom kitchens with waterproof cabinets, and cabinets that are independent of the benchtop so that the cabinets can be lifted out to allow cleaning.
- Electrical Services. Recommendations for the meter board and all other services to be raised above the flood level.

A key observation of each of these is that they are targeting only one component of a house. If flood resilient flooring were incorporated, for example, this does not protect the walls. Similarly, if a flood resilient kitchen is installed, it does not provide any protection for the walls. Therefore, each element that is installed as flood resilient is effectively only providing "protection" for that specific element.

Further, as identified above, the majority of the retrofit measures do not deal with the structural resilience of the house. For larger depth, longer duration flooding, this can become more important. Collier et al (2021), for example, raised this as a particular concern on the Hawkesbury-Nepean floodplain where there are relatively large depth ranges between AEP events. Therefore potentially these types of retrofit measures may only be appropriate for smaller inundation depths (say up to 1 – 1.5m and low velocity type environments).

6.3.2 Cost of Resilience

Some representative examples of flood resilient measures are provided in Table 9, together with indicative cost rates based on Rawlinsons (2019).

Table 9. Example Flood Resilient Measures

Element	Base		Resilient Option		% Difference in Cost
	Material	**Cost**	**Material**	**Cost**	
Wall - Insulation	Glasswool	$9 – 10 per sqm	Polystyrene	$28 per sqm	200%
Wall – Linings	Fibreboard	$25 per sqm	Fibrecement	$41 per sqm	60%
Flooring	Carpet	$72 per sqm	Tiles	$120 per sqm	67%
Door	Hollow core	$142 per door	Solid Core	$200 per door	40%

Based on the estimates in Table 9, and adopting a typical single storey house, flood resilient measures are likely to cost an approximate $20,000 extra compared with the non-resilient measures, an overall 80% increase in cost compared with the non-resilient measures.

A review was also undertaken on the available literature, with a brief overview of the different estimates provided in Table 10.

Based on the above, retrofitting of flood resilience may be in the order of $20,000 - $40,000 additional compared with the non-resilient alternative, although it would be highly dependent on the existing dwelling and the ability to retrofit the house.

Table 10. Summary of Cost Estimates - References

Source	Country	Cost Estimate	Comments
QRA (2019)	Australia	$30,000 to $50,000	For new build, not retrofit.
Keating et al (2019)	UK	$30,000 to $50,000	Retrofit. Includes resilient plaster, removable doors, internal wall rendering, resilient kitchen, raised electrics and appliances. Excludes flooring.
Keating et al (2019)	UK	$50,000 to $80,000	As above, but with resilient flooring
Blue Book – Single Storey	Australia	$10,000	New build. Appears to be on the low end of estimates.

6.3.3 Reduction in Damages

Both QRA (2019) and Collier et al (2021) report on economic assessments of flood resilience. In the case of Collier et al (2021), the assessment was based on new construction. In this situation, the choice becomes between the baseline cost of purchasing a relatively standard material (e.g. carpet as a floor covering) versus spending on the flood resilient alternative (e.g. tiles as a floor covering). In other words, the assessment is on the incremental cost of the flood resilient measures.

Collier et al (2021) found that full resilient measures, inclusive of both structural and non-structural measures, were generally economically viable for events more frequent than the 1 in 50 AEP. However, an independent assessment of the non-structural resilient components was not undertaken as a part of Collier et al (2021).

QRA (2019) also undertook an economic assessment on flood resilience. However, in that situation, the assumption was that the resilient measures would result in a 70% reduction in building contents damages in a flood. It is not clear how the resilient measures that were proposed would result in a reduction in building contents damages.

The Blue Book (HNFMSC, 2006) estimated that the reduction in damages as a result of improving the flood resilience of buildings was in the order of 25% at 1.2m of overfloor flooding. However, the basis of this assumption is unclear and it is likely to still be focused on the savings associated with a new build.

There has been effort in the United Kingdom (UK) on research into this area, with a focus on resilient retrofitting of existing dwellings. However, the housing stock in the UK is typically different to Australian housing stock, which can lead to some challenges in direct comparisons. However, it does provide a general indication of potential benefits. Thurston et al (2008) undertook some work on the potential damages under 'resistance' options (e.g. flood barriers) and flood resilience (e.g. flooring, power points etc). The damage curves from this work are presented in Figure 19. These damage curves would indicate that building resilience measures resulted in a reduction of approximately 38% in damages with no flood resilient flooring, and 55% with flood resilient flooring.

Based on the work of Thurston et al (2008), the 'Multi-Coloured Handbook' for economic assessments in the UK (Penning-Rowsell et al, 2013) recommends an assumed £67.74/m^2 reduction in damages as a result of flood resilient measures. This was based on an average of with and without resilient flooring, but is based on a typical UK style detached dwelling. However, given the difficulty in scaling this to Australian conditions, an estimate of 38 – 55% is probably more reasonable to adopt for Australian conditions.

Kriebich (2002) estimated the influence of flood resilient measures in Germany. This looked at a range of measures, including for buildings with water barriers and the influence of basements on flood damages. Some of the resilient measures included change in use of rooms below the flood level, in addition to resilient materials. This makes it difficult to compare directly. However, resilient measures such as having services (e.g. electrical utilities) above the ground floor resulted in reductions in damages of around 36%.

QRA (2019) undertook an estimate of the reduction in damages due to flood resilience. The key assumption was that "internal damages" (assumed to be contents damages, consistent with the terminology in the Brisbane River Flood Study) would be reduced by 70%, but that there would be no saving in external or building damages. It was not clear as to the basis of this assumption, and this does not appear to agree with some of the other research. It is unlikely that internal damages, which include furniture and other items, would be reduced by this much.

A summary of some of the literature is provided Table 11. Overall, the reduction in building damages may be in the order of 25 – 50%.

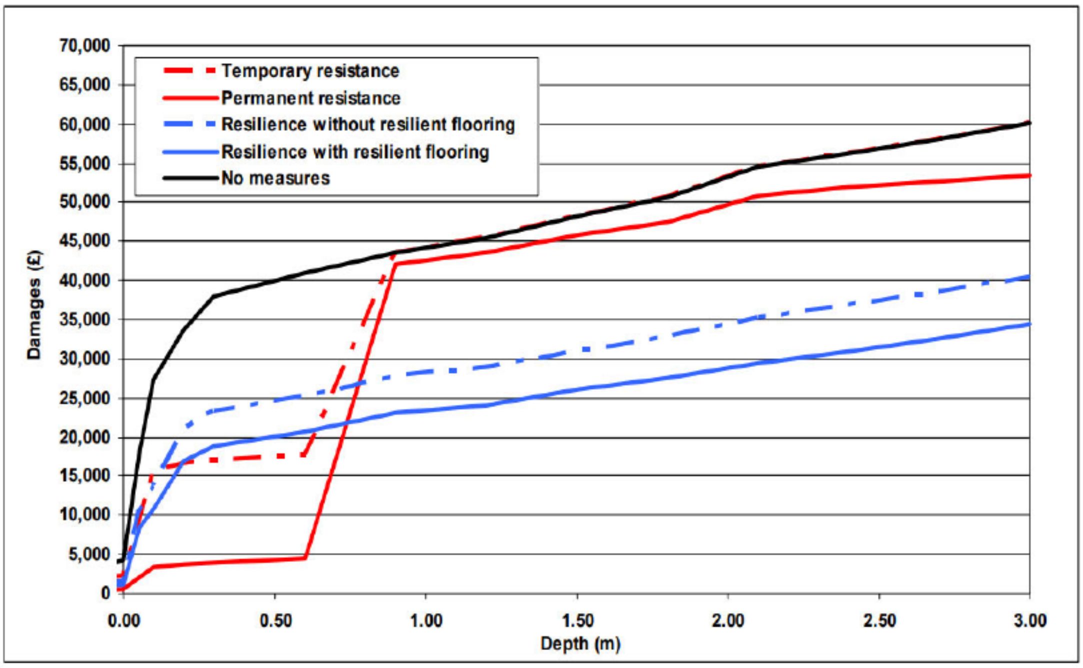

Figure 19. Damage Curves from Thurston et al (2008)

Table 11. Reduction in Building Damages - Literature

Source	Country	Reduction in Building Damages (%)
Kriebich (2002)	Germany	36%
Thurston et al (2008)	UK	38 - 55%
Blue Book - Single Storey	Australia	26%
Blue Book - two storey	Australia	24%

6.3.4 Economic Assessment – Materials

Based on the outcomes of the above, a review was undertaken on the economic viability of retrofitting resilient materials within a building.

As noted above, each resilient measure effectively provides protection or resilience for that particular component. Therefore, one way of viewing the assessment is on the financial question of whether it is more appropriate to spend money on flood resilience now, or to replace the building material each time it floods.

Two scenarios have been considered:

- Scenario 1 – retrofitting of the building is undertaken independent of a flood event. In this situation, the existing building materials are replaced even though there is no damage to them.
- Scenario 2 – retrofitting of the building is undertaken after a flood event. In this situation, the choice is whether to incorporate resilient materials or normal materials, as the existing materials need to be replaced. Therefore, it is the incremental cost of the resilient materials that is a key consideration.

In assessing these scenarios, one way to analyse this is on a unit cost approach. Under this approach, the question is the limit in additional cost of the resilient material compared with the non-resilient material that would be used. This is shown in Figure 20.

The key outcomes from this analysis are:

- Retrofitting an existing home under Scenario 1 when no flooding has occurred, and the existing house materials are serviceable, is unlikely to be viable. As most resilient materials are at least 50% more expensive than their non-resilient alternative, it would only be economically viable when the floor level of the house is at or below the 1 in 5 AEP level.
- Under Scenario 2, the outcome differs as the materials need to be replaced regardless after the flood event. On the basis that most resilient materials are at least 50% more expensive than their non-resilient alternative, then flood resilient materials are more likely to be viable for floor levels that are at a 1 in 20 AEP flood, or more frequent event.
- Should the cost of flood resilient materials fall to less than 1.25 times their non-resilient alternative, it may be economically viable to retrofit homes up to the 1 in 50 AEP extent, which would greatly increase the applicability of flood retrofitting to a larger number of homes.

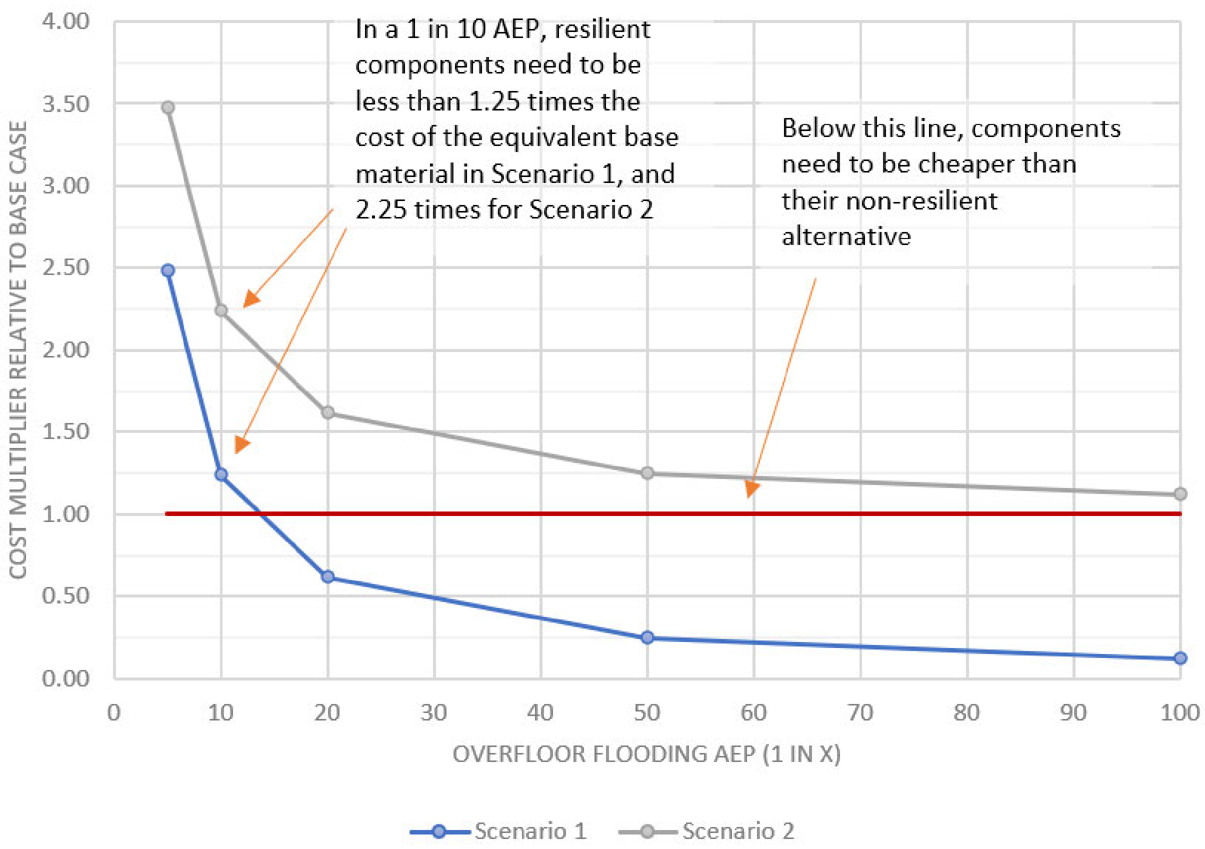

Figure 20. Flood Resilient Cost Multipliers

6.3.5 Economic Assessment – Case Study Areas

In addition to the above, an assessment was undertaken on the case study areas identified in Section 6.2. As noted in Section 6.2, there are a high concentration of properties within one or two AEP ranges of overfloor flooding in some of the study areas. Therefore, the analysis was undertaken across all properties in all representative areas.

The analysis has been undertaken on the basis of Scenario 2 above, where resilient measures are incorporated into the building after a flood event. Therefore, the key cost is the incremental cost of the resilient measures.

The assessment was undertaken on the basis of the mid-range cost estimates for resilience (approximately $30,000). A mid-range assumed reduction in building damage (around 38%) was adopted, although an estimate of 10% of the building damage was assumed to be associated with external damages and therefore unaffected.

The results of this analysis are summarised in Figure 21.

Individual properties can be highly variable their BCR results, dependent on the level of flood affectation etc. However, Figure 21 suggests that for properties with a floor level at or below the 1 in 10 AEP, flood resilient measures are generally economically viable. For properties with a floor level between 1 in 10 AEP and 1 in 20 AEP, then there would be some situations (or floodplains) where flood resilient measures would be viable.

Figure 21 shows some very high BCR values. These appear to be associated with areas of very high depth flooding in even frequent events and may therefore not be entirely representative. As noted in Section 6.2, a hypothetical dwelling with a floor level of 0.4 metres above ground has been assumed. However, there are some properties with high depths in the 1 in 10 AEP event. In reality, these may be constructed as high-set or Queenslander style dwellings.

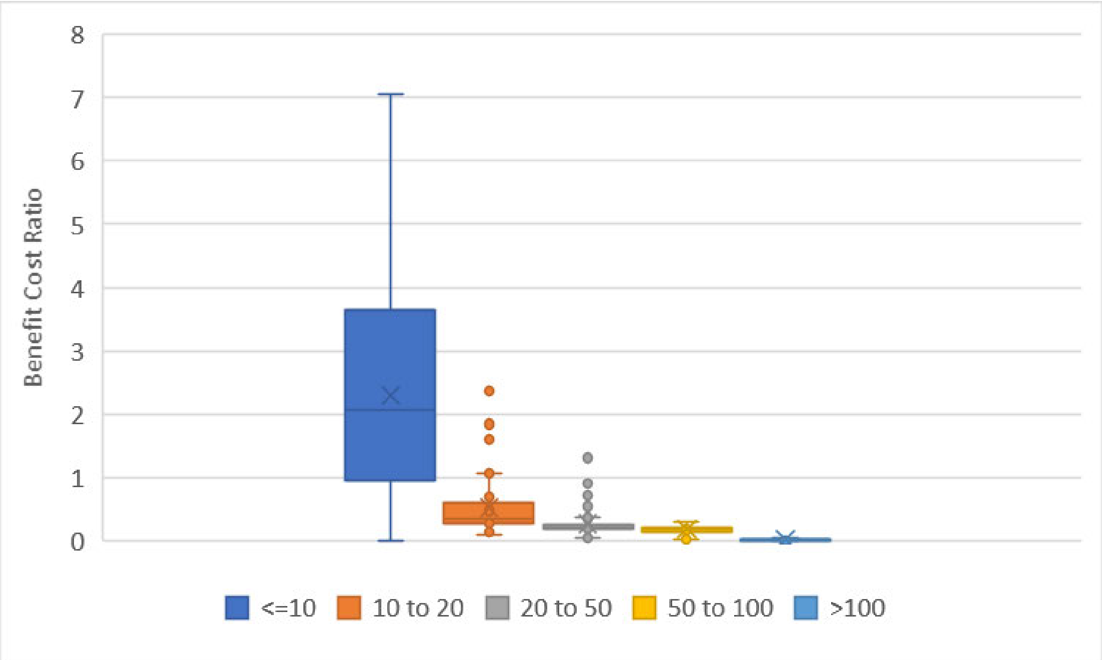

Figure 21. Flood Resilient BCR Results at Different Floor Levels

The economic analysis above is focused on the viability of the flood resilient measures. However, there remains relatively significant "residual" damages that are possible for a property even after residual measures have been incorporated. On average, across all the AEPs, there remains around 80% of the total damage, inclusive of building, contents and intangibles. In other words, the residual measures provide around 20% reduction over the total damages.

6.3.6 Large Scale Resilience Program

The analysis above is based on the retrofit of an individual dwelling. If a large-scale program were adopted, inclusive of a large-scale take-up of that program, then there may be cost efficiencies and cost reductions for resilience.

Ginger et al (2021) identifies that in 2019 the Queensland Household Resilience Program, which focuses on resilience in cyclone areas (such as roof improvements), led to significant reductions in retrofit costs (from $35,000 to $20,000, roughly just over a 40% reduction in cost).

The BCR was recalculated for a similar proportional reduction in cost, with the results shown in Figure 22. Under this scenario, then there is an improvement in the results overall, with improved performance of properties in the 1 in 10 to 1 in 20 AEP range.

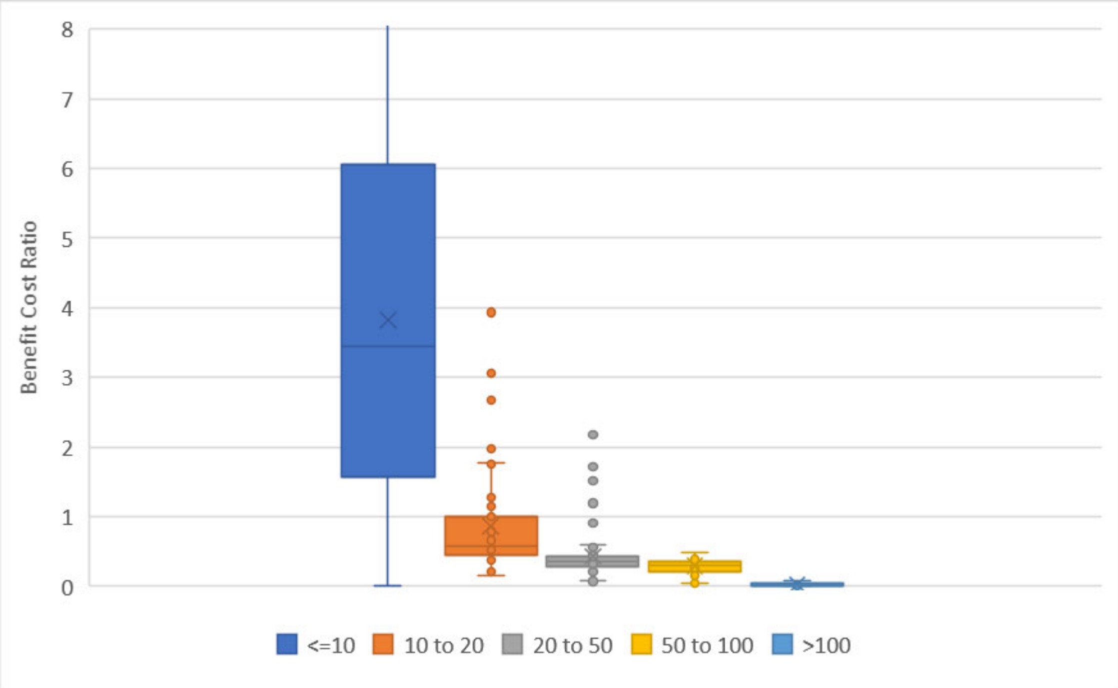

Figure 22. Flood Resilient BCR Results at Different Floor Levels – Large Scale Program

6.4 House Raising

House raising is an alternative property level mitigation where an existing property is raised. This is generally only viable for lightweight structures on piered foundations (e.g. timber). It provides some additional advantages over flood resilience, in that the contents of the property (at least those within the house) are protected. However, there remains an ongoing risk to life as well as external damages to the property itself.

There are some ongoing house raising schemes that have been implemented by various local government authorities. These typically involve some level of subsidy that is provided in order for an individual owner to raise their property.

The cost for raising a house is highly dependent on the type and size of the house, the land it is on, and to a lesser extent the height to which it is to be raised. Typical costs are in the order of $120,000 per house.

In addition to AAD values for the representative areas for a typical house with a floor level 0.4 metres above ground, IAG also provided AAD values for a range of other heights include for a typical house at 1.8 metres above ground, or in effect a house raised by 1.4 metres.

Using this information, an assessment was undertaken on the viability of house raising. Reductions in both building damages and contents damages were estimated based on the information provided by IAG. It is noted that no change to intangibles were made, as the resolution of the information would be difficult to estimate this. However, there is likely to be some further reduction in damages associated with intangibles (for example a house that is raised may not experience overfloor flooding and therefore may not cause the same issues to residents that an event where overfloor flooding has occurred).

No residual value was assumed beyond the 30 year economic assessment period. This is on the basis that the dwelling is not new at the start of the assessment, and the service life may not extend significantly beyond the 30 year horizon.

Figure 23 shows the results of the analysis. Similar to flood resilient measures, house raising is generally viable for properties with a floor level at or below the 1 in 10 AEP.

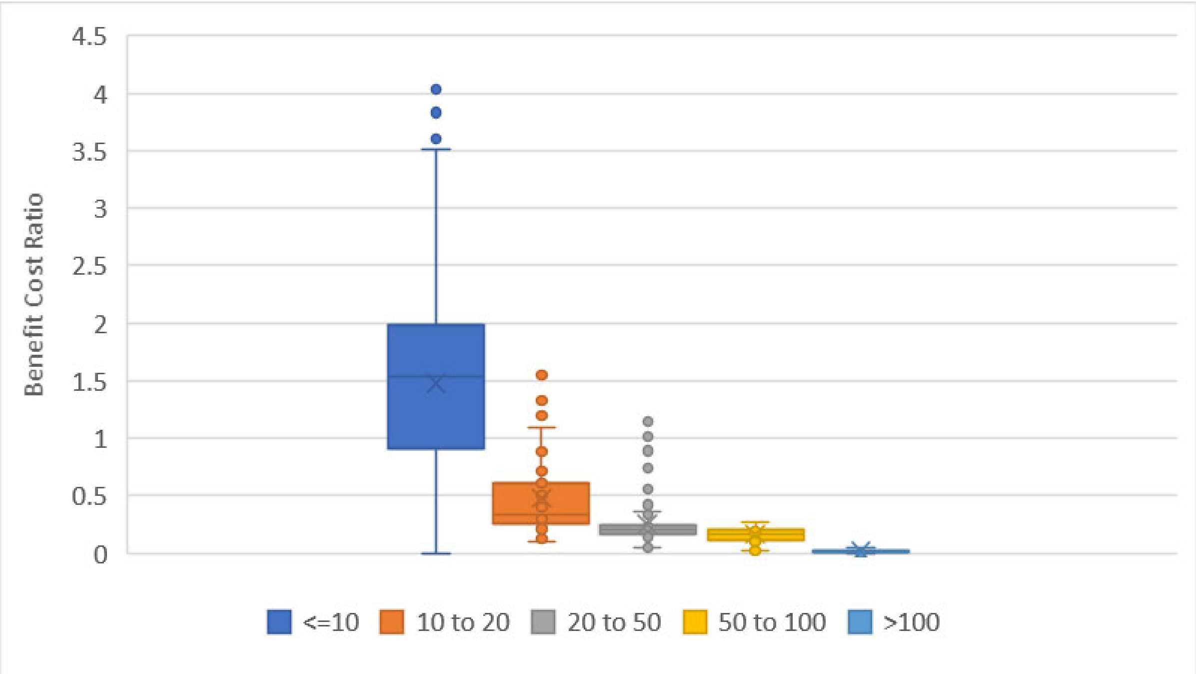

Figure 23. House Raising Benefit Cost Ratio

As with the flood resilience, this analysis has been undertaken on house raising for an individual dwelling. Traditionally, house raising programs have been undertaken at only a few houses at a time, and therefore there is unlikely to be significantly economies of scale. However, if a funding mechanism were implemented that allowed for larger scale roll-out of house raising, then potentially overall costs may reduce. An alternative scenario was analysed with a 40% reduction in cost. The results are shown in Figure 24.

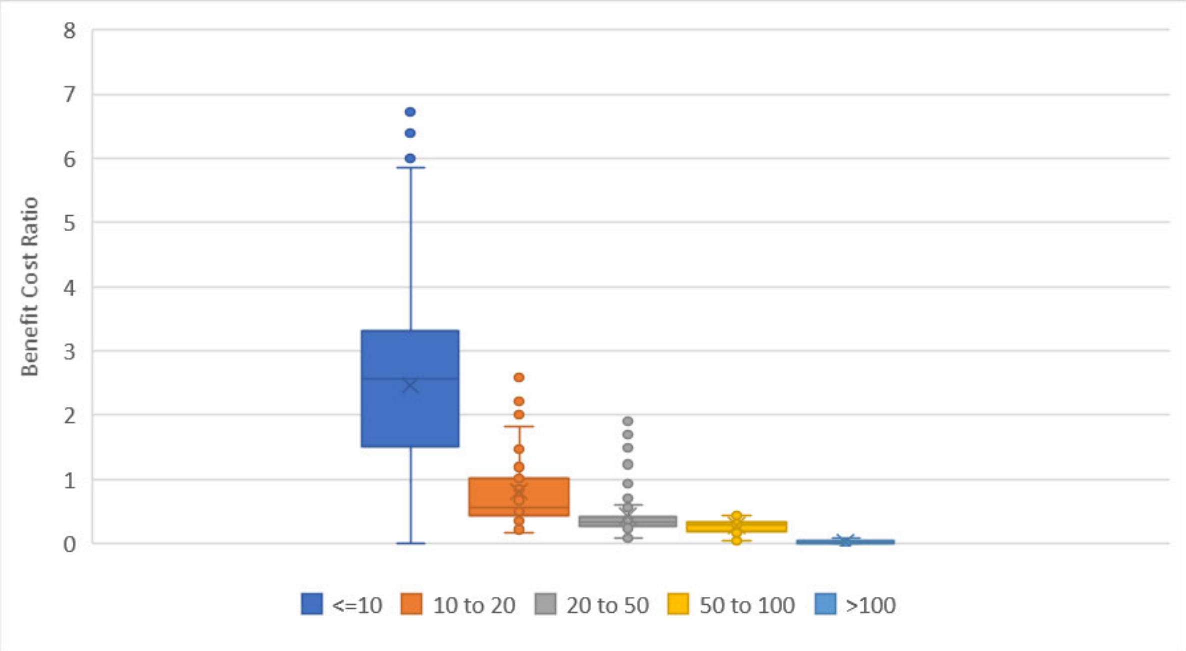

Figure 24. House Raising Benefit Cost Ratio – Large Scale Program

6.5 Land Swap

Under a land swap scheme, the relevant government authority identifies significant flood affected land, and seeks to coordinate an opportunity for those landowners to "swap" their land for a flood free area. Examples of this include a local government swapping an open space (park) area that is not flood affected for a residential dwelling allotment(s) with an existing house(s) (and demolishing the house(s) to create a parkland area). This can have the advantage of not only removing the dwelling from the flood affected area, but also improving flow conveyance by removing the obstruction of the dwelling. Generally, these schemes have typically only been applied in high risk (e.g. high hazard) flood areas and where vacant land is available to enable the swap to occur.

The key benefits are the removal of not only the property damages, but also the risk to life from people being located within the floodplain. The economic benefits considered in this assessment include the building, contents and non risk to life intangibles as identified in **Appendix A**. For the purposes of this analysis on land swap, the risk to life component has not been included given the difficulty in quantifying this with any degree of accuracy at a property scale.

From a cost perspective, effectively the land is "exchanged", and therefore there is no real loss in land value. However, the landowner is required to construct a new house on the new parcel of land. House cost estimates, as provided by IAG for the different areas, were included within the assessment. An additional allowance of 20% of the house value was also incorporated to allow for demolition of the existing dwelling and potential other costs associated with creation of a new open space.

The economic assessment period was extended beyond 30 years to 50 years, to represent the likely design life of the new house.

The results of the analysis are summarised in Figure 25.

The benefit cost ratio is largely below 1 for all scenarios. However, there are additional considerations for land swap, such as removal of a property from a high hazard area (and hence risk to life and evacuation considerations) or wider improvement of conveyance (and hence reduction in flood damages to surrounding properties). These have not been incorporated within this analysis (as they require specific details on the flood behaviour at the individual properties and their surrounds). Therefore, there is likely to still be merit in this type of scheme under certain conditions. Some examples of this may include:

- Following a flood event, where the existing dwelling has suffered significant structural damage;
- Where homes can be relocated intact (rather than new build) for relatively low cost;
- Where risk to life is extreme and removing homes from the floodplain is warranted, and achieves additional benefit that has not been quantified here;
- Where erosion is likely to cause loss of land and rebuilding may not be feasible;
- Where land is to be reclaimed to improve the function of the waterways and provide benefits to the broader floodplain;
- Where the site is impacted by multiple compounding hazards (such as bushfire).

Following the above, a sensitivity analysis was undertaken for the situation where a house is significantly damaged by a flood event, and requires reconstruction. In this situation, the house would need to be reconstructed regardless. Therefore, the cost of land swap is more around the preparation work on the new land as well as the establishment of the open space area. The results of this sensitivity analysis are shown in Figure 26, which would suggest under these much lower costs the land swap is a viable option for properties with a floor level below the 1 in 10 AEP. BCR values are also relatively high for the 1 in 10 to 1 in 20 AEP floor level range, suggesting that there may be floodplains where this is viable, particularly considering the additional factors that have not been included in this analysis.

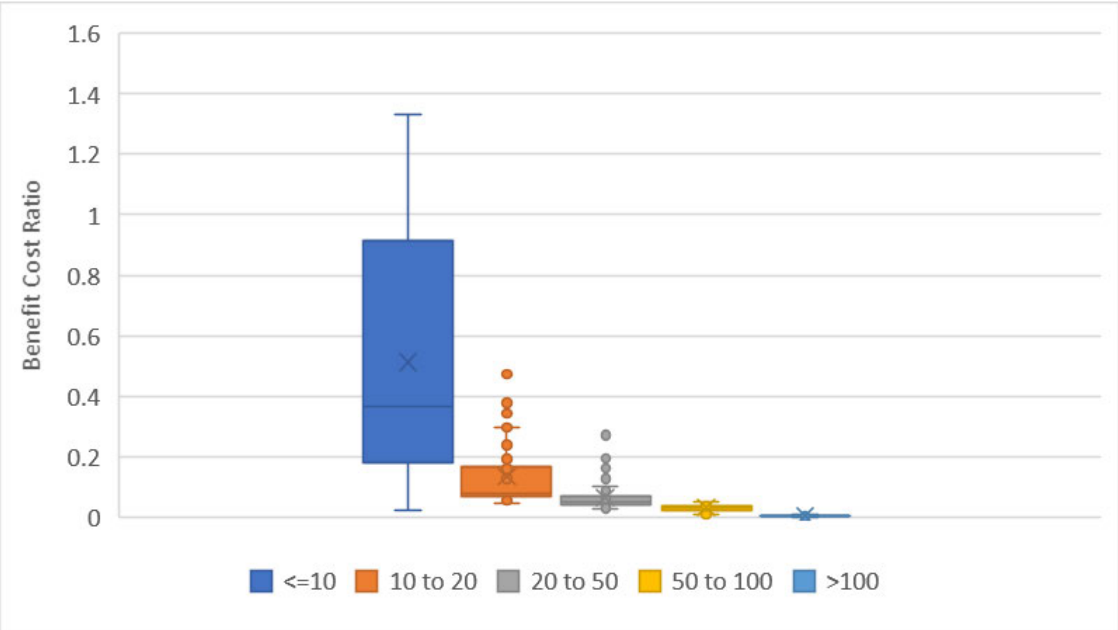

Figure 25. Land Swap Benefit Cost Ratio

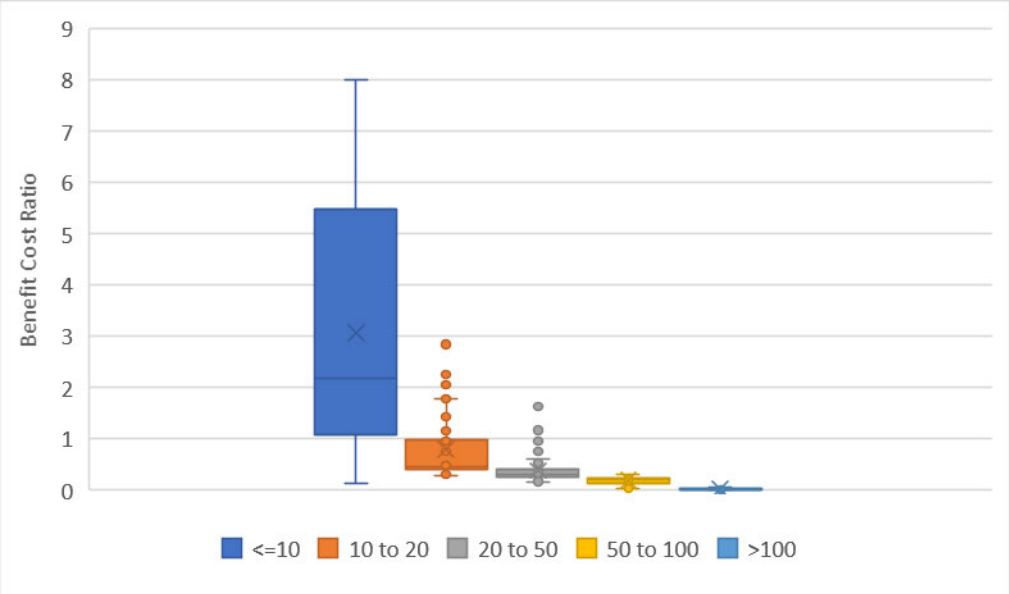

Figure 26. Land Swap Benefit Cost Ratio - Exclusion of House Cost

6.6 Summary

The above analysis has largely demonstrated that flood resilience and house raising are largely viable where property floor levels are at or below the 1 in 10 AEP. This may be further improved if a large-scale program were adopted that could achieve cost efficiencies. However, both options only deal with a portion of the overall flood damages, as well as the risks associated with the property being located in the floodplain. A high level comparison of how the components that the options deal with is presented in Table 12.

Land swap, provides the most "comprehensive" reduction in flood damages and flood risks, but has a lower economic performance. However, as noted, there are additional considerations that have not been included in this analysis, including:

- The reduction in risk to life for the household, as well as the evacuation considerations and demands on emergency services;
- The potential improvement in flood conveyance through the removal of the property, and the associated benefits to other properties as a result;
- For very high hazard flows, the potential risk of partial or full structural failure of the dwelling;
- Where the house can be relocated at relatively low cost, rather than the need to construct a new house;
- Following a flood event, where the existing dwelling has suffered significant structural damage.

Under these types of conditions, land swap may be a viable alternative to be considered.

A sensitivity analysis was undertaken on the scenario where a property experience significant structural damages and requires replacement following a flood event. If the land swap were to occur at that point in time, then the analysis suggests that it would be viable for a floor level less than 1 in 10 AEP, and potential marginal for a 1 in 10 to 1 in 20 AEP. As per the discussion above, other considerations (such as the risk to life and flood conveyance improvements) may result in an improved outcome.

Table 12. Property Mitigation Summary

Mitigation Type	Direct Damage		Indirect Damages		Intangibles	
	Building Damages	Contents Damages	Cleanup Costs	Relocation	Risk to Life	Other
Flood Resilient Building (Retrofit)						
House Raising						
Land Swap						

Low/ No Reduction	
Partial Reduction	
Large Reduction	

7 Conclusions

This report has investigated two key components:

- Identification of potential structural flood mitigation measures (also known as flood modification measures in some jurisdictions) in short-listed floodplains across the country, and an economic assessment of these measures;
- A review of potential property level mitigation measures, such as flood resilience and house raising, and an economic assessment of these measures.

The short-listing process for the floodplains was based on IAG damage information together with stakeholder and literature review. Strategic level flood mitigation measures were identified for the short-listed floodplains, and a preliminary economic assessment was undertaken for each floodplain. The preliminary economic analysis suggests that the mitigation measures would be economically viable.

The above analysis has largely demonstrated that flood resilience and house raising are largely viable where property floor levels are at or below the 1 in 10 AEP. This may be further improved if a large scale program were adopted that could achieve cost efficiencies. However, both options only deal with a portion of the overall flood damages, as well as the risks associated with the property being located in the floodplain.

Land swap provides the most “comprehensive” reduction in flood damages and flood risks but has a lower economic performance. However, as noted, there are additional considerations that have not been included in this analysis, including:

- The reduction in risk to life for the household, as well as the evacuation considerations and demands on emergency services;
- The potential improvement in flood conveyance through the removal of the property, and the associated benefits to other properties as a result;
- For very high hazard flows, the potential risk of partial or full structural failure of the dwelling;
- Where the house can be relocated at relatively low cost, rather than the need to construct a new house;
- Following a flood event, where the existing dwelling has suffered significant structural damage.

Under these types of conditions, land swap may be a viable alternative to be considered.

7.1 Limitations

The approaches adopted in this assessment are appropriate for strategic level economic estimation. Further detail and refinement would be required should the identified potential mitigation measures progress further.

The methodology adopted places a large degree of reliance on the underlying damages dataset provided to Rhelm by IAG. It has been assumed that this data is fit for purpose and representative of the damages for each area.

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1 Lismore (NSW)

1.1 Locality

Lismore is located in the northern rivers region of NSW, about 730 km north of Sydney. The Lismore LGA has a population of 43,667, of which around 25,000 are within the Lismore township[1]. Lismore is located on the confluence of the Wilsons River and Leycester Creek which can result in flooding from either system. The short-listed study area for Lismore is shown in Figure 1.

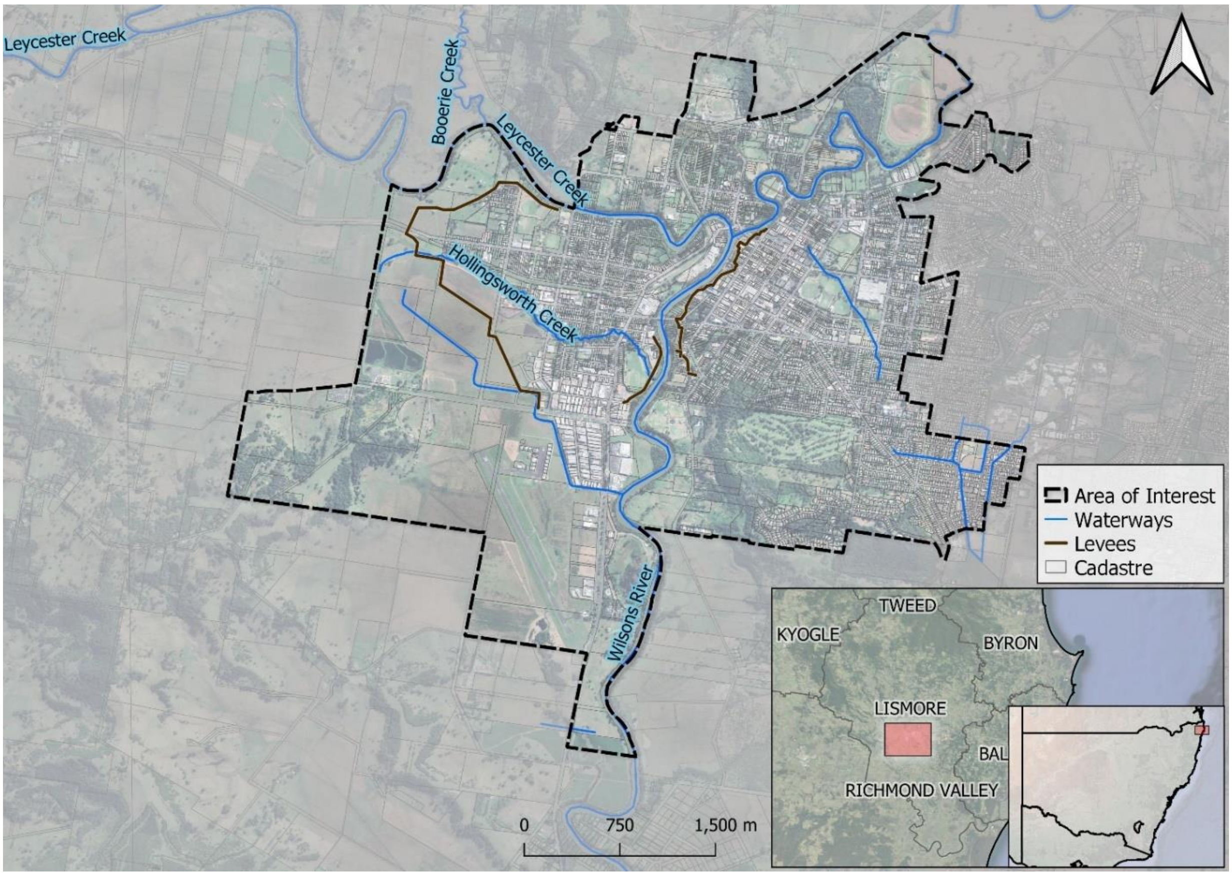

Figure 1. Lismore Locality

1.2 Flood Behaviour

The Lismore FRMSP (Engeny, 2020) has recently been completed which assessed the flooding for Lismore and developed potential mitigation options. An extract of the 1 in 100 AEP flood depth is shown in Figure 2. In the 1 in 100 AEP event Lismore has significant flooding with flood mitigation being overtopped and depths within the township of up to 5m.

Lismore currently has levee protection for the CBD portion of the township as well as for South Lismore. These levees are shown in Figure 3. Both levees have low levels of protection and are expected to overtop in events from the 1 in 10 AEP and greater. Recently these were overtopped in the 2017 flood event, Figure 4 and Figure 5 show large scale flooding for Lismore during this event.

[1] Based on Lismore City Council profile - https://profile.id.com.au/lismore

There are also a number of floodgates, pump systems and increase channel conveyance mitigation measures in place.

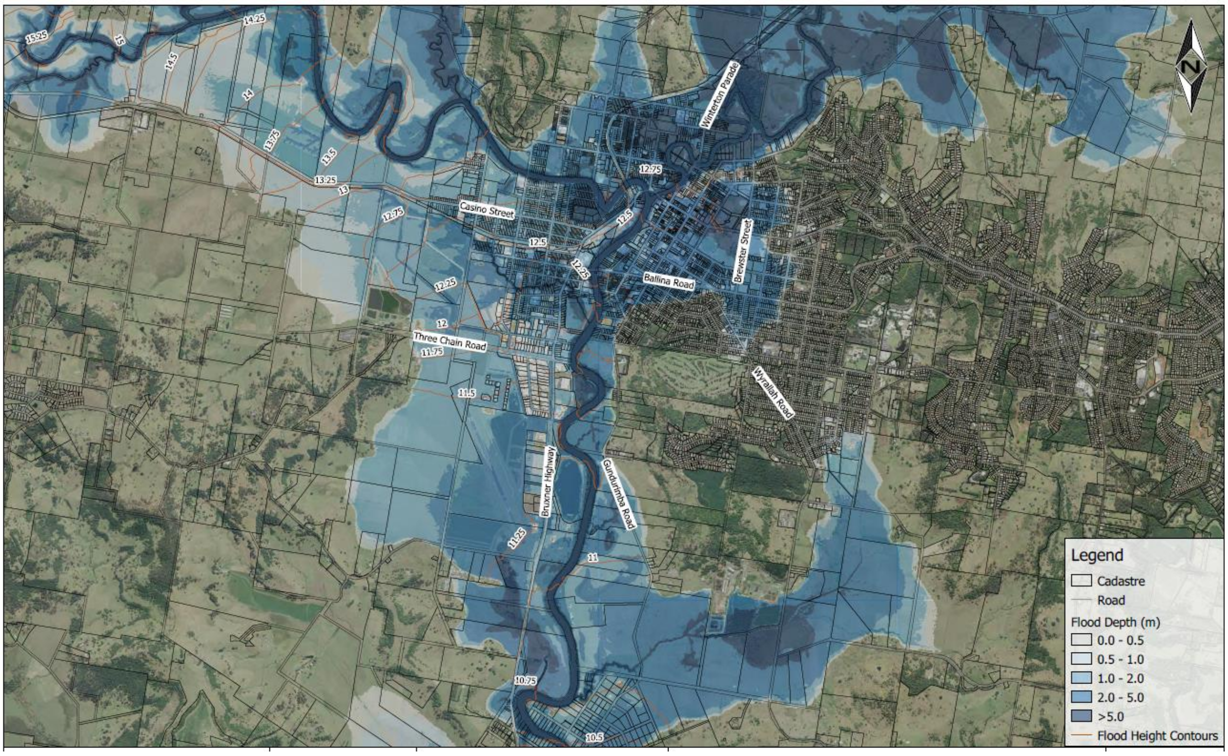

Figure 2. Lismore 1% AEP flood depths (Engeny, 2020)

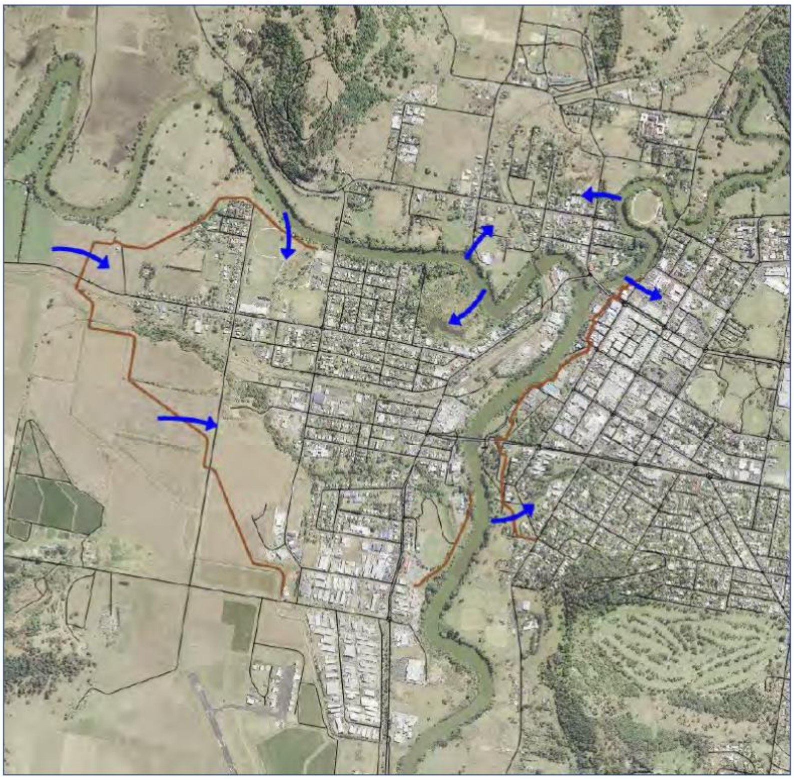

Figure 3. Lismore levees and flooding inundation direction (Engeny, 2020)

Figure 4. Flooding in Lismore in 2017 (ABC News: Ruby Cornish)[2]

Figure 5. Flooding in Lismore in 2017 (AAP: Dave Hunt)[3]

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[2] https://www.abc.net.au/news/2017-03-31/in-photos:-floods-devastate-northern-nsw/8403958

1.3 Potential Mitigation

The analysis in this report was completed in August 2021, prior to the flooding in the NSW Northern Rivers region in early 2022. We acknowledge that there is ongoing work being undertaken by Lismore City Council, CSIRO, the Northern Rivers Reconstruction Corporation, NSW and Federal Governments and the National Recovery Resilience Agency to mitigate against flood risk and build community resilience in Lismore. Given this ongoing work, analysis on potential mitigation measures has not been undertaken on Lismore.

2 Shepparton (VIC)

2.1 Locality

Shepparton is located in north central Victoria, approximately 181 km north of Melbourne. It is a large centre with a population of 51,631 (including Mooroopna)[5]. Shepparton is a region hub and is a centre for large industry operations including companies such as SPC Ardmona and Campbells Soup Company. It is located at the confluence of the Goulburn River, Broken River and Seven Creeks and each of these systems can cause flooding within the township. It is a complex floodplain nework with the timing and magnitude of each system influencing the potential impacts on the community.

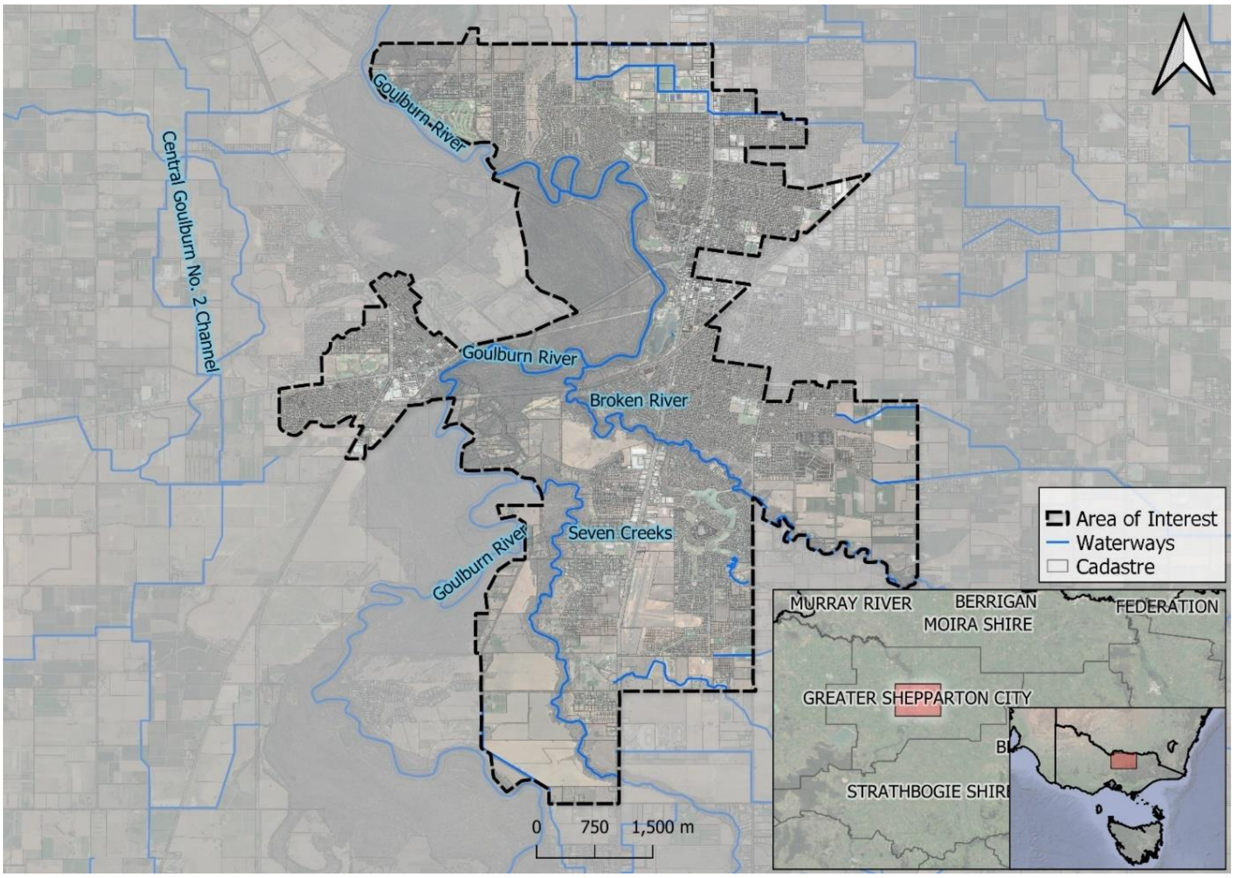

Figure 6. Shepparton Locality

2.2 Flood Behaviour

A recent study has been completed, the Shepparton Flood Mapping and Intelligence Report (Water Technology, 2019) providing a contemporary evaluation of flood behaviour through the township for a range of events. These include a Goulburn River dominant, Broken Creek dominant and Seven Creeks dominant events. These events are then enveloped to form the expected 1% AEP event.

[5] *3218.0 – Regional Population Growth, Australia, 2017-18: Population Estimates by Significant Urban Area, 2008 to 2018". Australian Bureau of Statistics. Australian Bureau of Statistics. 27 March 2019.* Estimated resident population, 30 June 2018.

The combined flood result is shown in Figure 7. Across Shepparton and Mooropna there is widespread flooding, although most overbank flooding is less than 1m in depth.

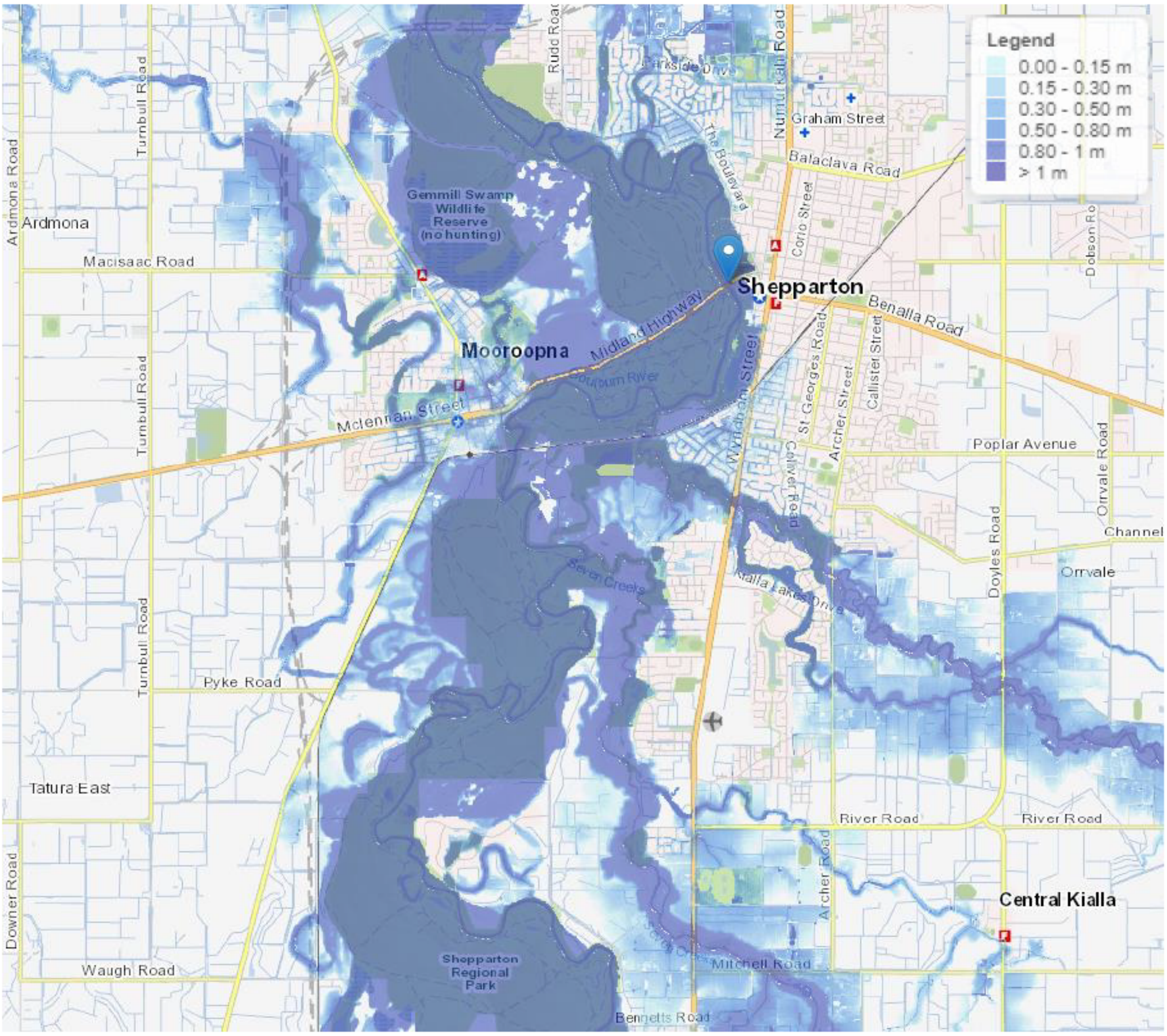

Figure 7. Shepparton 1% AEP flood conditions (Water Technology, 2019)[6]

Further to the 2019 Water Technology study there has been a Shepparton East specific study completed (BMT WBM, 2017) and an older Shepparton-Mooroopna Flood Study (SKM, 2002) which covered a similar area to the 2019 study. Each of these studies has completed a flood damage assessment as part of the analysis. The Shepparton-Mooroopna Study (SKM, 2002) included a damage assessment and mitigation option assessment.

2.3 Mitigation

Mitigation options have been developed from assessment of the current flood study results (Water Technology, 2019) and from options developed in the Shepparton-Mooroopna Flood Study (SKM, 2002). The 2002 Flood Study assessed several flood mitigation options but due to changes in flood levels (impacts associated with the levees) the mitigation options were not developed further. It is also

[6] http://www.floodreport.com.au/

understood that during the 2002 study, that there were some community objections to the proposed levees, although it is not clear if that sentiment remains.

The SKM (2002) assessment was on the basis of 1 in 100 AEP protection provided by the levees. Therefore, a lower protection of 1 in 50 AEP has been considered for the purposes of this strategic design, as it may be easier to offset any increases in flood levels or changes in flood behaviour. However, flood modelling would be required to refine this. For example, a protection at a 1 in 20 AEP level, whilst protecting less properties, may result in less afflux.

The mitigation options developed as possible protection measures include:

- South Shepparton Levee
- South Mooroopna Levee
- Kialla Levee
- Boulevard Levee
- Kialla Lakes levee
- Riverside / Shopping Centre levee
- East Mooroopna Floodway - Increased waterway opening in causeway and railway line crossing.

The mitigation options are presented in Figure 8 and with more description in Table 2.

Table 1. Descriptions for proposed mitigation options for Shepparton

Mitigation Option	Potential Protection	General Description
South Shepparton Levee	1 in 50 AEP	Earth levee, ~2m in height. One major road crossing. Levee length of around 4.3km long.
South Mooroopna Levee	1 in 50 AEP	Has two major road crossings. ~1.5m in height, total length around 2.5km long.
Kialla Levee	1 in 50 AEP	Open land, less constraints for construction. ~1.5m height. 0.6km long.
Boulevarde levee	1 in 50 AEP	Reasonably open earth levee, 1 major road crossing. ~1.5-2m in height, 4.9km long.
Kialla Lakes	1 in 50 AEP	Low levee ~1.5m in height, required road redesign. 1.3km long.
Riverside / Shopping Centre	1 in 50 AEP	~1m in height, 0.5km in length.
East Mooroopna Floodway	Increased conveyance of floodway	Roughly 64,000 m^3 to be excavated and a large bridge widening on a major road. Identified in the SKM (2002) study to offset impacts of levees.

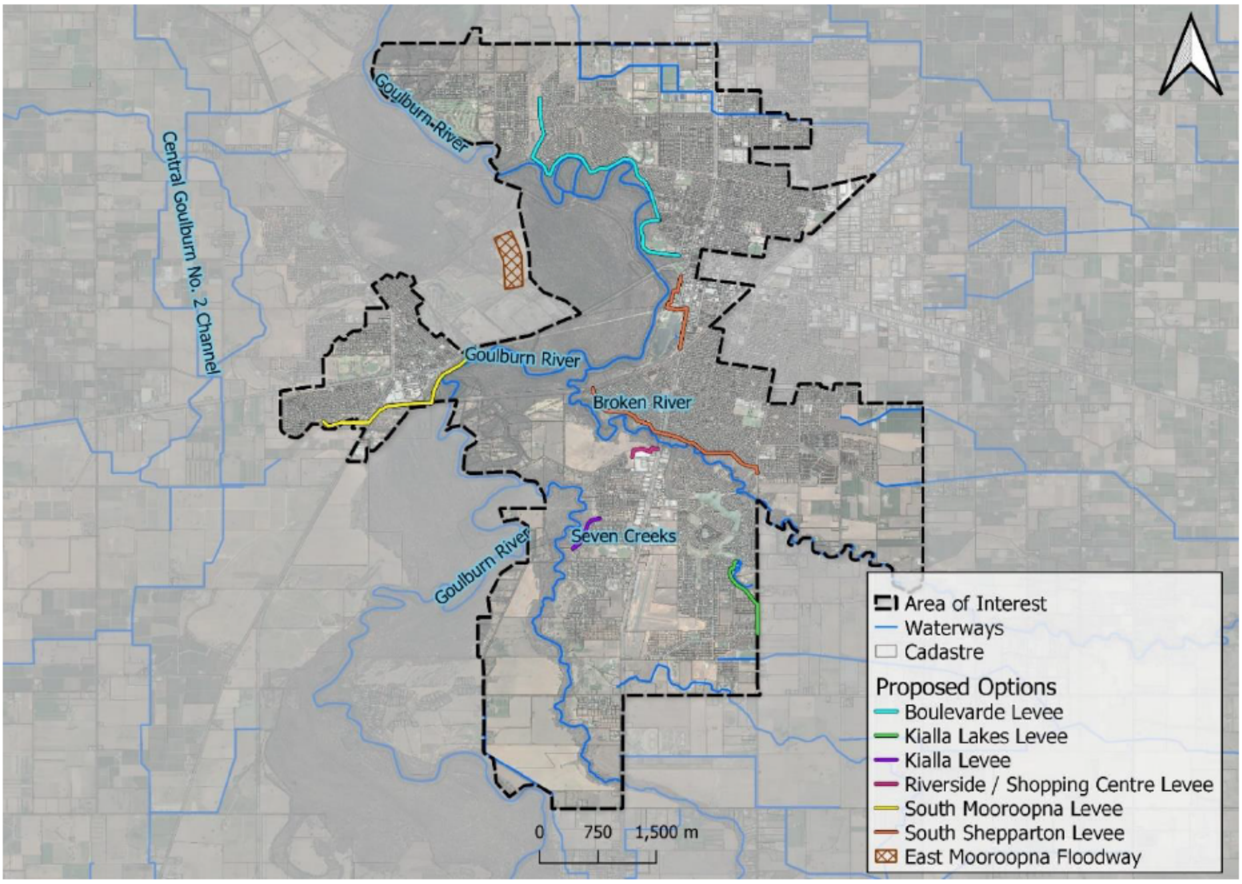

Figure 8. Shepparton mitigation options

2.4 Costing

The proposed mitigation options have been costed based on similar levee development in other locations, road crossing and an estimate of how complex the levee would be to construct. Costs are summarised in Table 2.

Table 2. Estimated costs for proposed mitigation options for Shepparton.

Mitigation	Description	Cost ($m)
1	South Shepparton Levee	$9.7
2	South Mooroopna Levee	$3.9
3	Kialla Levee	$0.7
4	Boulevarde levee	$7.9
6	Kialla Lakes	$3.5
7	Riverside / Shopping Centre	$0.3
8	East Mooroopna Floodway	$3.0
	Total	**$28.9**
	Contingency (65%)	**$18.8**
	Total with contingency	**$47.7**

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2.5 Current Status

The Shepparton mitigation options are strategic only. They were assessed in the SKM study in 2002, however new modelling has been undertaken since that time and no updated assessment of the mitigation works has been undertaken. The findings in 2002 indicated that there were widespread increases in flood levels with the development of the flood mitigation and since the SKM (2002) study no further assessment has been undertaken.

A detailed investigation would be required to understand the impacts of the mitigation as well as concept design to understand the limitations of the mitigation options.

2.6 Key Considerations and Uncertainties

Previous mitigation analysis for Shepparton indicated that the mitigation was likely to have unacceptable impacts across the broader floodplain. The feasibility of the mitigation options would need to be understood prior to further consideration and design.

Previous mitigation identification and assessment resulted in poor community acceptance of intervention works. More indirect methods were utilised to manage the future risk to the floodplain, such as increased planning controls and improved on-site detention policies.

2.7 Summary

Shepparton is well understood to have a large flood risk with significant damages in rare flood events. There is a large range of potential mitigation options available for protecting the township which makes it a suitable location for further consideration. However, a limitation is the sensitivity of the floodplain to mitigation options and community acceptance for the mitigation works.

Table 3. Shepparton - Summary

Item	Description
Level of Design	Strategic. While the mitigation was assessed in 2002 (with a higher protection), no update to this assessment has been undertaken
Flood Mitigation Performance	Targeting a 1 in 50 AEP protection for those areas protected by the levees. May be required to lower this protection if negative flood impacts.
Cost Estimate	**$47.7M** Strategic only.
Constraints	• Potential environmental constraints, particularly for the floodway • Uncertain on community acceptance of the scheme
Further Work Required	A flood risk management study to undertake appropriate optioneering and community engagement.

3 Narrabri (NSW)

3.1 Locality

The Narrabri study area is located within the Namoi River floodplain and is drained by a number of smaller tributaries including Mulgate Creek, Horsearm Creek and Long Gully. Narrabri has experienced above floor flooding from each of these sources on a regular basis in the past. Flooding is complicated through the township, as the Namoi River splits upstream of the township, with low flows continuing in Namoi River and higher flows bypassing down Namoi Creek.

The locality of the Narrabri is shown in Figure 9. This figure shows the split of the Namoi River system.

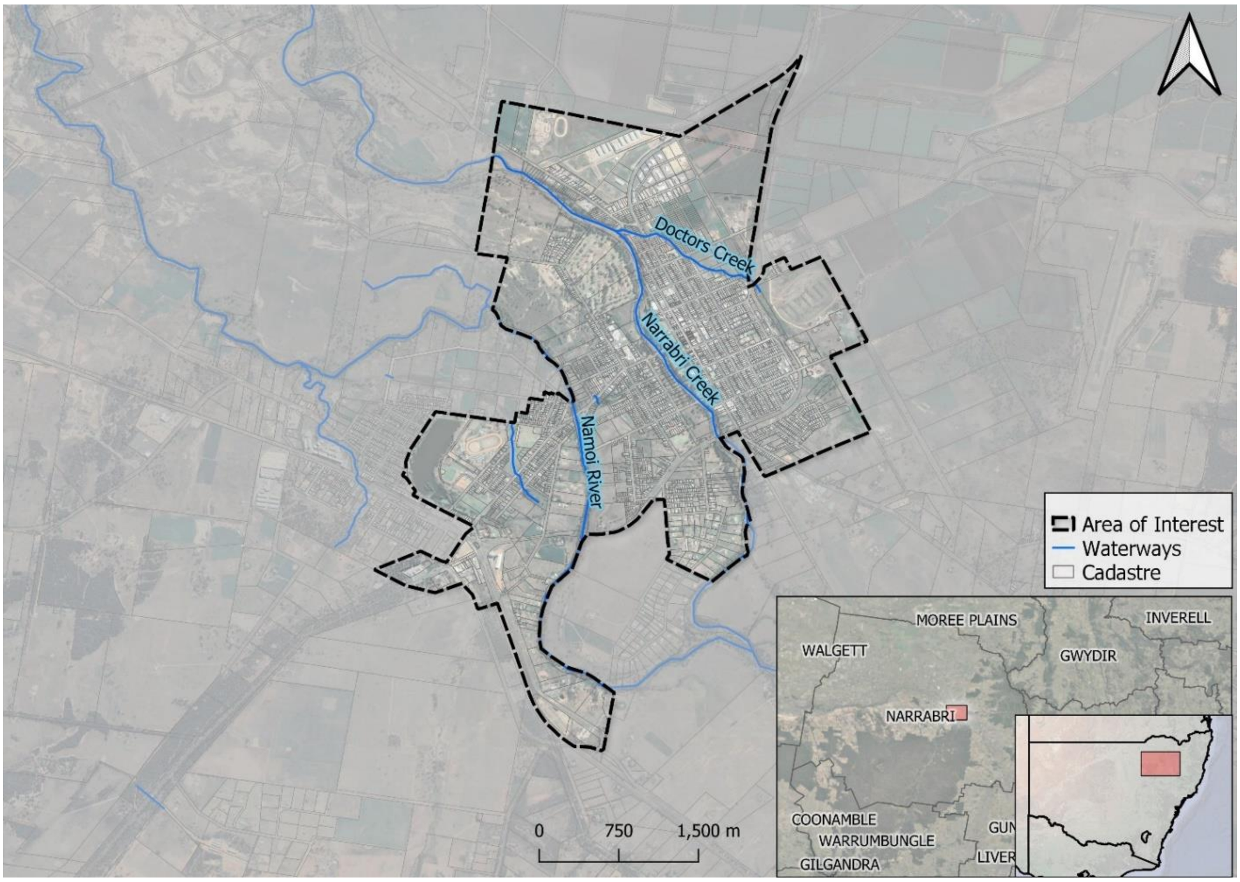

Figure 9. Narrabri Locality

3.2 Flood Behaviour

The current Narrabri Flood Study was completed in December 2016 by WRM Water Environment and updated in 2019. Narrabri is influenced by both regional flooding (Namoi River) and localised flooding (Narrabri Creek, Doctors Creek, Mulgate Creek, Horse Arm Creek and Long Gully). The 1% AEP local flooding (i.e. flooding driven from local creeks such as Horse Arm Creek) is shown in Figure 10, and the regional flooding (driven by the Namoi River) is shown in Figure 11.

The study indicated that there are around 5,000 properties impacted by flooding in the area, with over 180 homes and businesses expected to have overfloor flooding in the 1% AEP event for the local catchment flood, and over 1200 for the regional flood (WRM Water Environment, 2016). At the time of issue of this report the FRMSP had not been completed (but is underway). It is unknown when this is likely to be completed. From the flood study it is evident that much of Narrabri is impacted during events from the 20% AEP and is significantly impacted for events from 2% AEP and larger.

Local flooding results in shallow depths experienced throughout the main township, whereas regional flooding results in widespread flooding within Narrabri with depth of around 0.5-1.0 m.

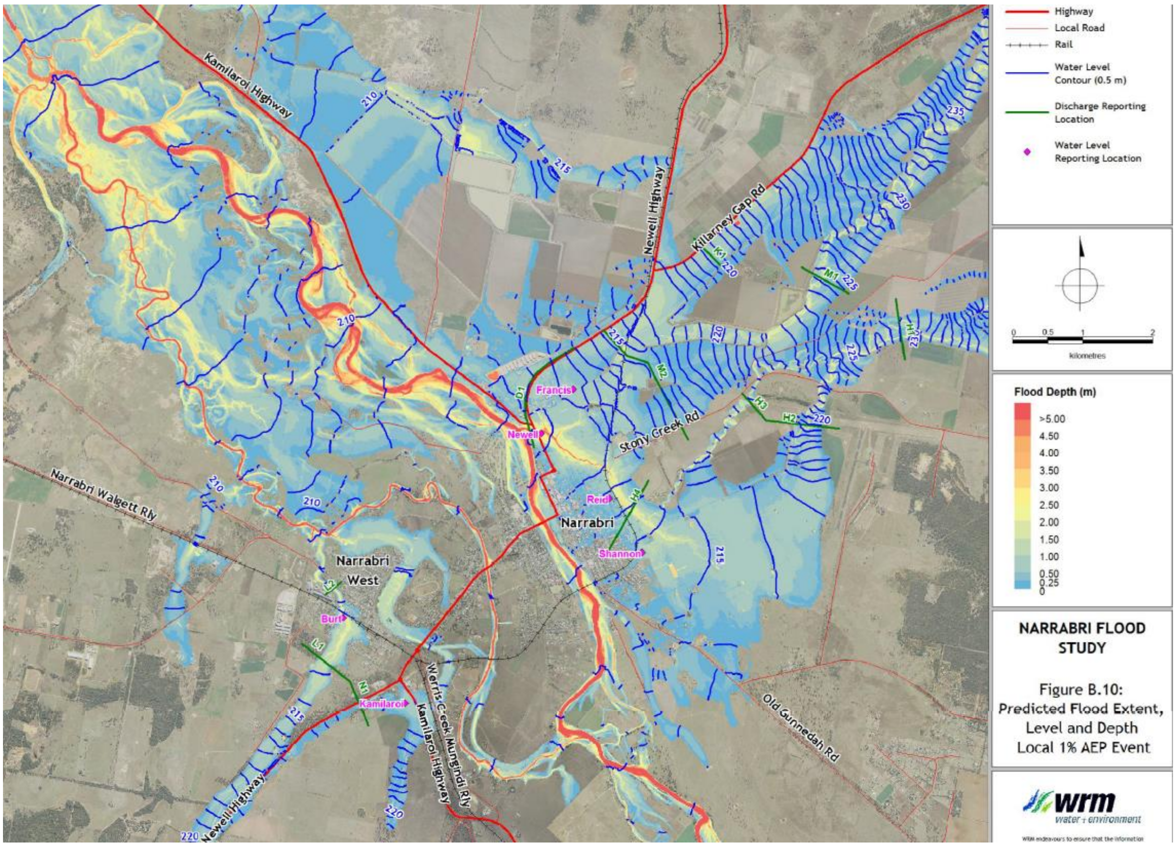

Figure 10. Narrabri 1% AEP flood conditions for local events (WRM Water Environment, 2016)

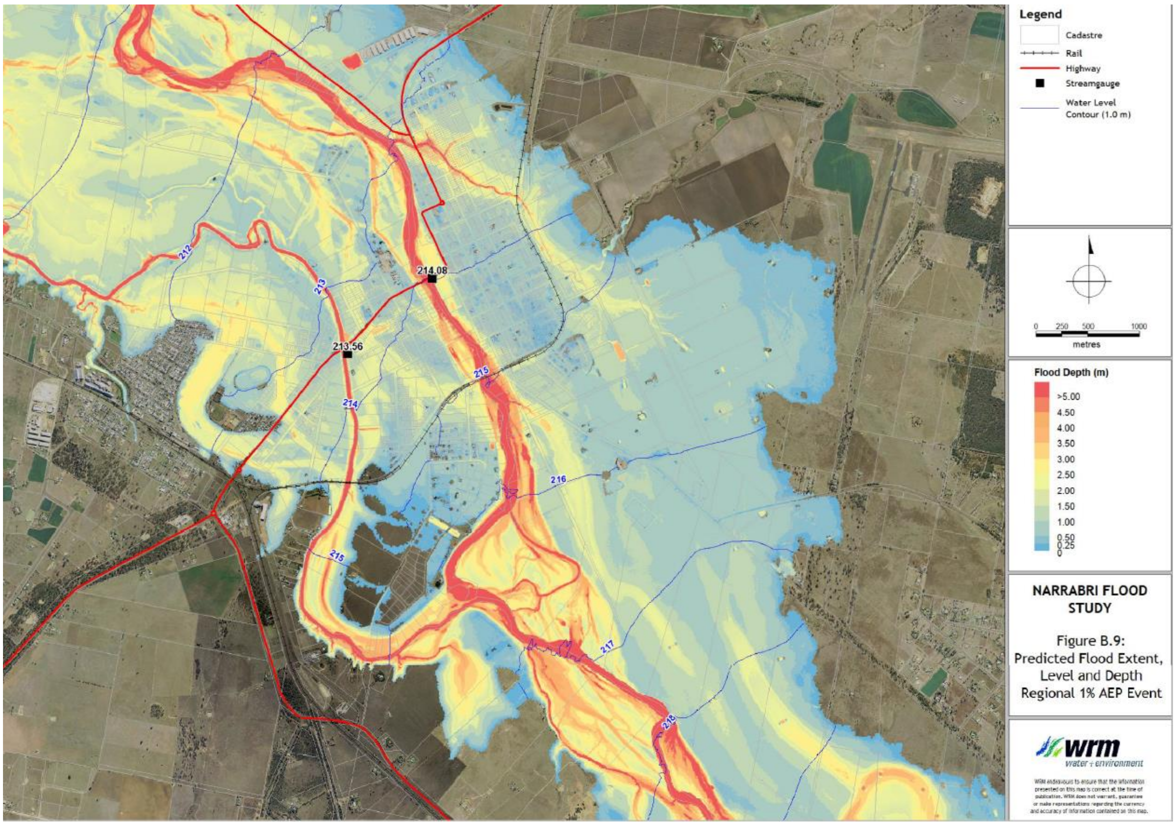

Figure 11. Narrabri 1% AEP flood conditions for regional events (WRM Water Environment, 2016)

An animation of the 1% AEP flood can be viewed by the following link:

https://www.youtube.com/watch?v=6f_Ue25Qx8Q&ab_channel=NarrabriShire

Aerial imagery of a significant flood event in 2004 is shown in Figure 12 and Figure 13. Figure 12 shows the influence of a levee and culverts on Horse Arm Creek. Figure 13 shows the Francis Street Industrial Estate.

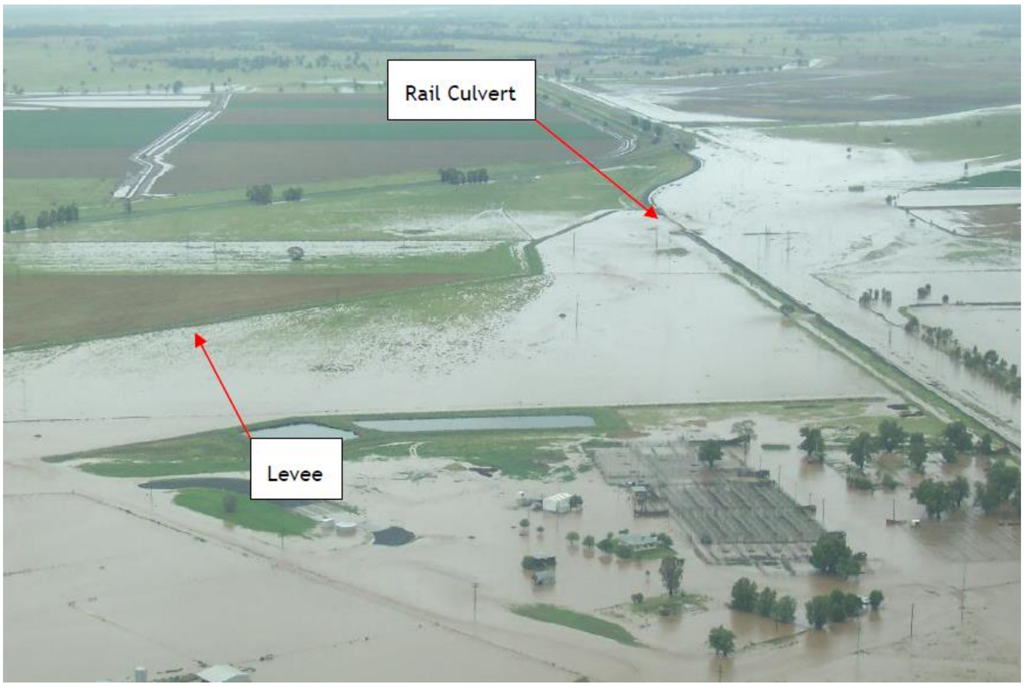

Figure 12. Aerial image of the 2004 flood for Narrabri (within Horse Arm Creek)[7]

Figure 13. Aerial image of the 2004 flood for Narrabri of the Francis Street Industrial Estate[3]

[7] Narrabri Flood Study (WRM water and Environment, 2016)

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3.3 Potential Mitigation

Narrabri is affected by extensive flooding with no major mitigation works within the main township. Flooding of the township occurs in events as frequent as frequent as a 1 in 10 AEP event and can be caused by either regional floods on the Namoi River system or local flooding from the smaller creeks in the area.

There is currently a FPRMSP in development, but this has not been completed and therefore there are no publicly identified mitigation works. As there are no current floodplain mitigation strategies investigated, the mitigation options developed have been based on available flood mapping and the underlying DEM for the township and as a result are only conceptual. The proposed mitigation options are shown in Figure 14 with additional details of the mitigation options summarised in Table 4.

Table 4. Narrabri flood mitigation options

Option	Proposed protection[8]	General Description
South East Levee	1 in 20 AEP	Earth levee ~2m in height, linking to the railway line, 1 road crossing, 1.8km
East Levee	1 in 20 AEP	Earth levee with some complicated sections, linking to rail line. ~2m high and 3 road crossings, 3.9km
Central Levee	1 in 20 AEP	Earth levee, ~1.5m high and 1 road crossing, 0.7km
Central Floodway Sth	1 in 20 AEP	Earth levee, ~1.5m high and 3 road crossings, 2.3km
Central Floodway Nth	1 in 20 AEP	Earth levee, ~1.5m high and 2 road crossings, 0.85km
West Levee	1 in 10 AEP	Earth levee, ~1.5m high and 2 road crossings (this levee may be difficult to implement), 1.6km
Industrial Levee	1 in 10 AEP	Earth levee, ~1.5m high and 2 road crossings (this levee may be difficult to implement), 1.9km
Channel widening / improved conveyance	N/A	Options to improve both Narrabri River and Narrabri Creek main channel conveyance. This has potential to alleviate any increases from proposed levee works.

[8] This could be higher or lower depending on impacts and what can be achieved by design

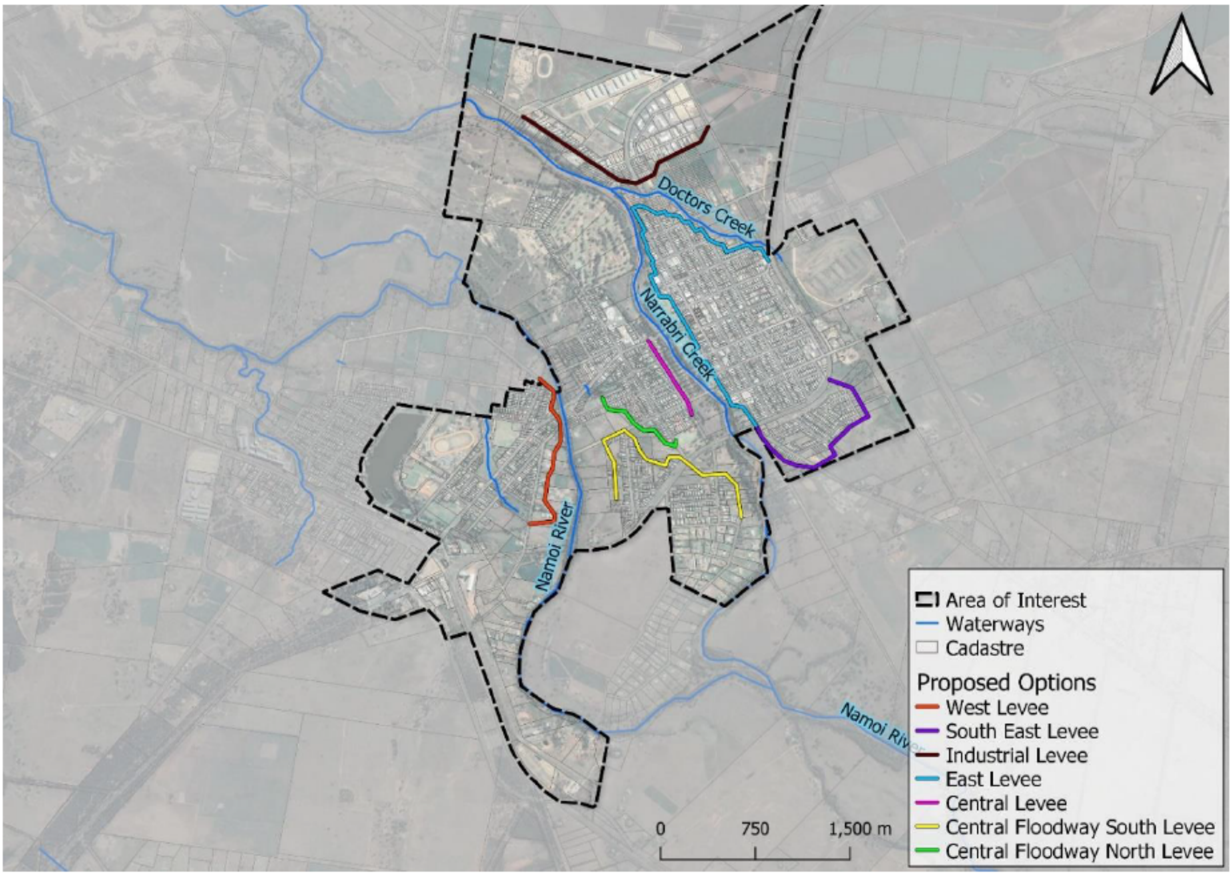

Figure 14. Potential mitigation options for Narrabri

3.4 Costing

The mitigations options considered have been costed using assumptions based on general levee project construction costs and cost estimates for completed projects across Australia. The costs are approximate only but give an indication of the expected scale of the works. A summary of the costs is suppled in Table 5.

Table 5. Costs estimates for Narrabri

Option	Proposed protection	Mitigation Indicative Estimated Cost ($m)
SE Levee	1 in 20 AEP	$5.0
East Levee	1 in 20 AEP	$11.1
Central Levee	1 in 20 AEP	$2.8
Central Floodway South	1 in 20 AEP	$5.7
Central Floodway North	1 in 20 AEP	$2.7
West Levee	1 in 10 AEP	$4.0
Industrial Levee	1 in 10 AEP	$4.5
	Total	**$35.8**
	Contingency (65%)	**$23.3**
	Total with Contingency	**$59.1**

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3.5 Current Status

All mitigation options for Narrabri have been developed as a concept only during this initial investigation. No assessment of the feasibility or acceptance of the proposed mitigation option has been undertaken. Mitigation options would require a detailed flood assessment, detailed costing, consultation and full detailed design prior to final adoption.

Council is currently undertaking a FPRMSP that is likely to identify a number of flood risk mitigation measures. The outcomes of this study should inform any future works in this study area.

The current status of Narrabri mitigation is **Strategic Only**.

3.6 Key Considerations and Uncertainties

The key consideration for Narrabri is that no formal investigation into mitigation options has been undertaken. The options developed are very high level and may produce impacts that are unacceptable to the community. It is unclear if levee options have been explored in the past or discussed at a strategic level for Narrabri as a part of their ongoing FPRMSP.

Flooding through the township is complex which may exacerbate the flood impacts on other areas due to the proposed mitigation options. Therefore, it will be important to ensure that appropriate flood analysis is undertaken.

3.7 Summary

The flood impact within Narrabri is high and the proposed mitigation options provide some protection to flood up to 1 in 10 to 1 in 20 AEP. There is uncertainty surrounding the impacts of the proposed mitigation options and with the community acceptance of flood mitigation works. The status of the options is strategic only and time and detailed studies would be required and approvals obtained before proceeding with works at this location.

Table 6. Narrabri - Summary Mitigation

Item	Description
Level of Design	Strategic. No formal modelling or investigation of mitigation options undertaken.
Flood Mitigation Performance	Targeting a 1 in 10 to 1 in 20 AEP protection for a number of areas in Narrabri. Potential for flood impacts on adjacent properties – modelling required to refine scheme.
Cost Estimate	**$59.1M**
Constraints	• Potential flood afflux • Several road crossings and interfaces with private properties • Environmental considerations are uncertain
Further Work Required	Floodplain risk management study and plan to be completed (currently in progress), including appropriate optioneering and community engagement.

4 Innisfail (QLD)

4.1 Locality

Innisfail is located approximately 73km south of Cairns, within the Cassowary Coast Regional Council LGA. It is located at the confluence of the South Johnstone and North Johnstone Rivers, which merge at Innisfail to form the Johnstone River.

The broader Innisfail area, which spans west and east of the rivers, has a population of over 7000 people, with around 3,200 dwellings[9]. A general overview of the locality is shown in Figure 15.

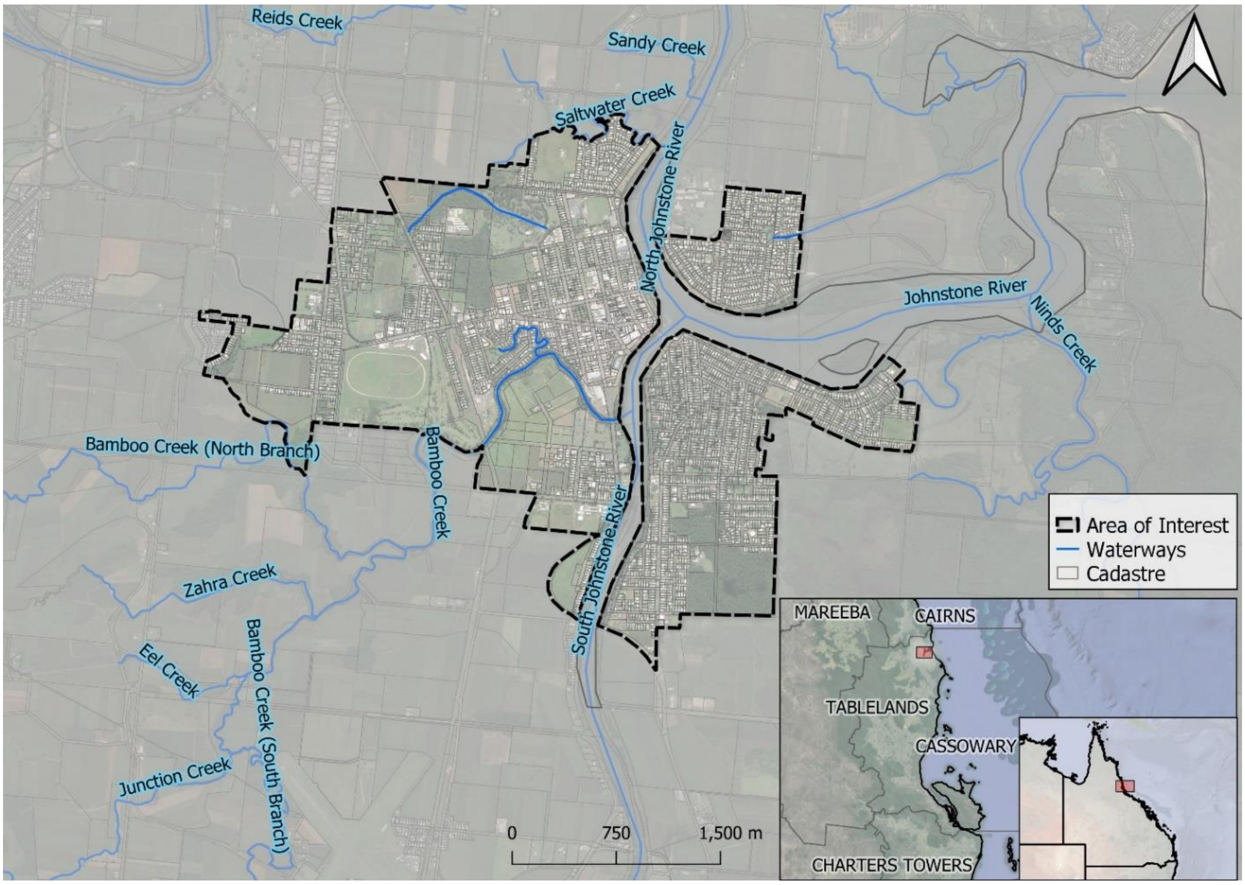

Figure 15. Innisfail Locality

4.2 Flood Behaviour

BMT WBM undertook a flood study in 2014 that incorporated the Johnstone River catchment and floodplain. A general overview of the flood depths for the 1 in 20 and 1 in 100 AEP are shown in Figure 16 and Figure 17.

Reviewing the flood behaviour, it would appear that more frequent flooding within the main township of Innisfail is driven by backwater flooding up tributaries such as Saltwater Creek and Sweeney Creek. The worst affected urban areas are parts of Innisfail, on the western side, as well as the suburb of Cullinane, which borders Saltwater Creek in the north. On the eastern side of South Johnstone River,

[9] https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/UCL314014

areas of Webb, South Innisfail and the southern parts of South Innisfail are affected. An overview of the terrain is provided in Figure 18, which provides a general understanding of these inundation areas.

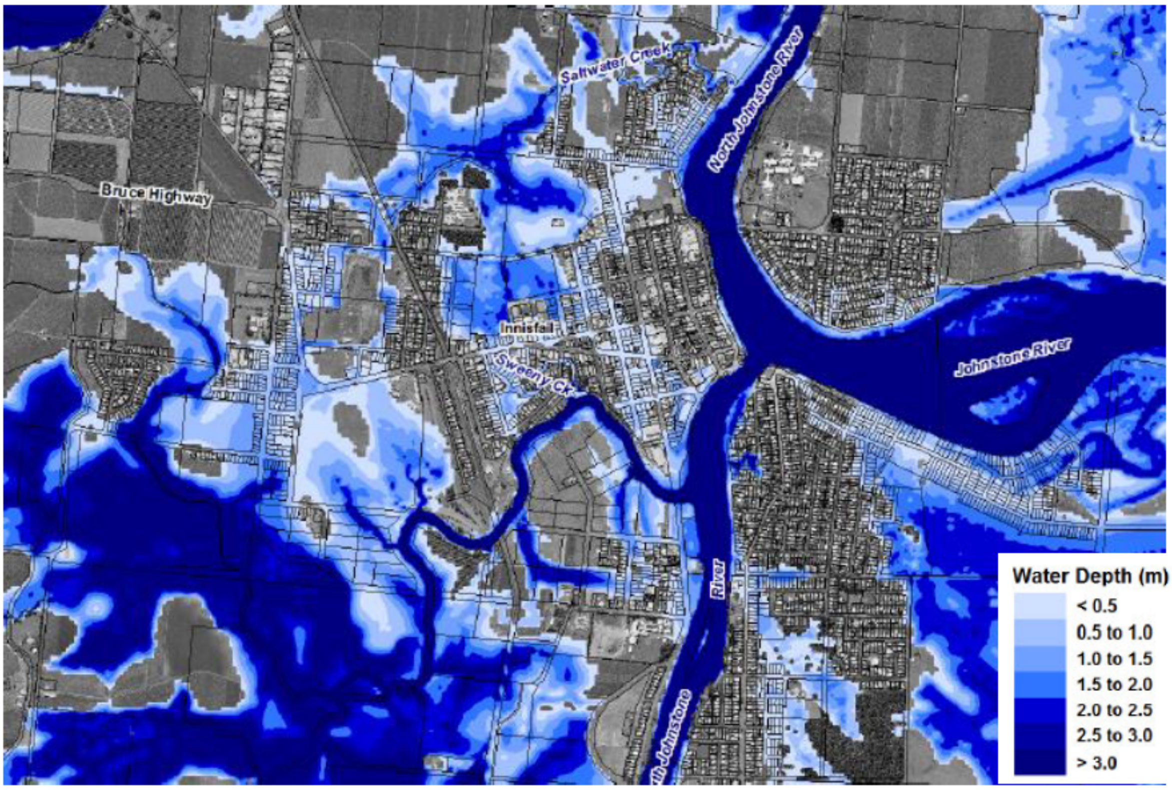

Figure 16. 1 in 20 AEP Flood Depth – Innisfail

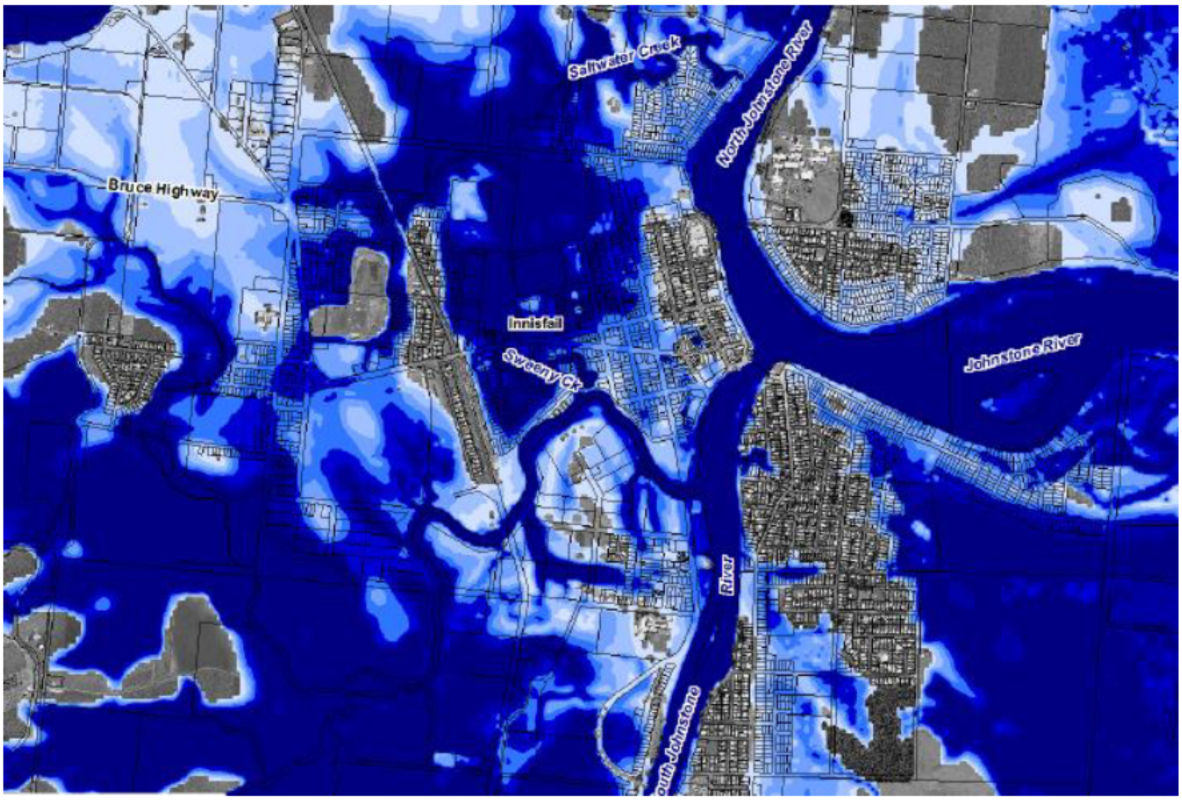

Figure 17. 1 in 100 AEP Flood Depth – Innisfail

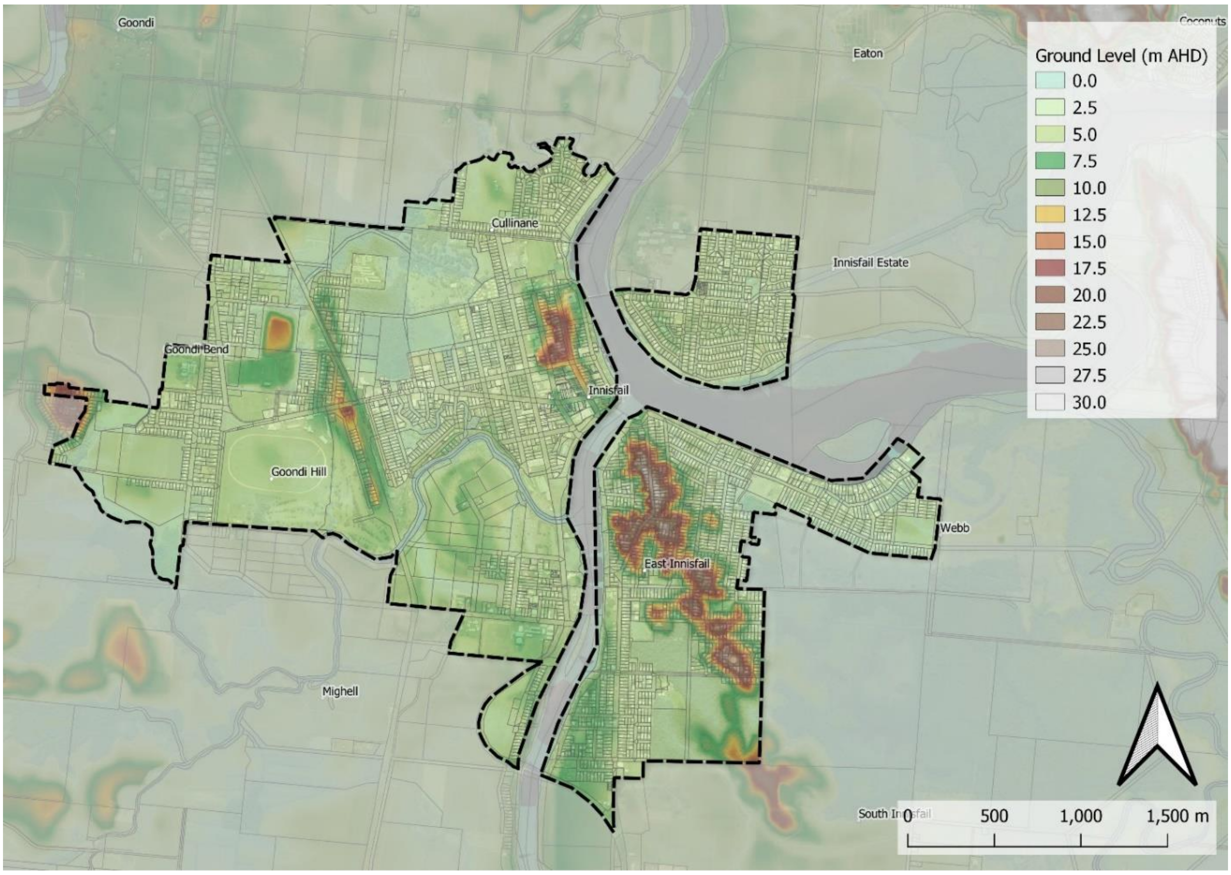

Figure 18. Overview of Terrain – Innisfail

4.3 Mitigation

Innisfail has had several investigations of potential flood mitigation options that have assessed levees, dredging and increased conveyance options. A selection of the more viable mitigation options has been identified that have potential to protect Innisfail without impacting the surrounding floodplain to unacceptable levels. The mitigation options identified are shown in Figure 19 and summarised in Table 7 along with a general description of the levee and mitigation option.

The proposed levees are set at a 1 in 50 AEP protection level, however this may not be achievable, and a lower level of protection may be required to be adopted. BMT WBM (2014) identified adverse impacts as a result of a 1 in 100 AEP levee scheme, and therefore a lower threshold of 1 in 50 AEP has been adopted in this report on the assumption that it may be easier to manage the potential flood impacts. A detailed study into the mitigation options should be undertaken to determine the feasibility of the options and the level of protection.

BMT WBM (2014) identified a potential dredging option for the river, which may have the potential to offset the afflux from the levees. This has been included in the overall mitigation option, although this should be reviewed depending on the necessity and afflux. Environmental considerations in particular in regard to this option will need to be considered.

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Table 7. Innisfail mitigation options description

Mitigation Option	Proposed Protection	General Description
South Innisfail	1 in 50 AEP	Earth levee, 0.5km long, requires a flood gate.
Goondi Hill Levee	1 in 50 AEP	Earth levee, 3.3km long, 2 road crossings.
Innisfail levee	1 in 50 AEP	Earth and concrete levee, 1.5km. Major road crossing and a flood gate.
Cullinane Levee	1 in 50 AEP	Earth levee, 3.1km long, includes a flood gate and multiple road crossings.
Dredging of Johnstone River - Large Scenario	Improved conveyance to off-set proposed levees	Dredging of the river, not well scoped but may offset the increases due to levees.

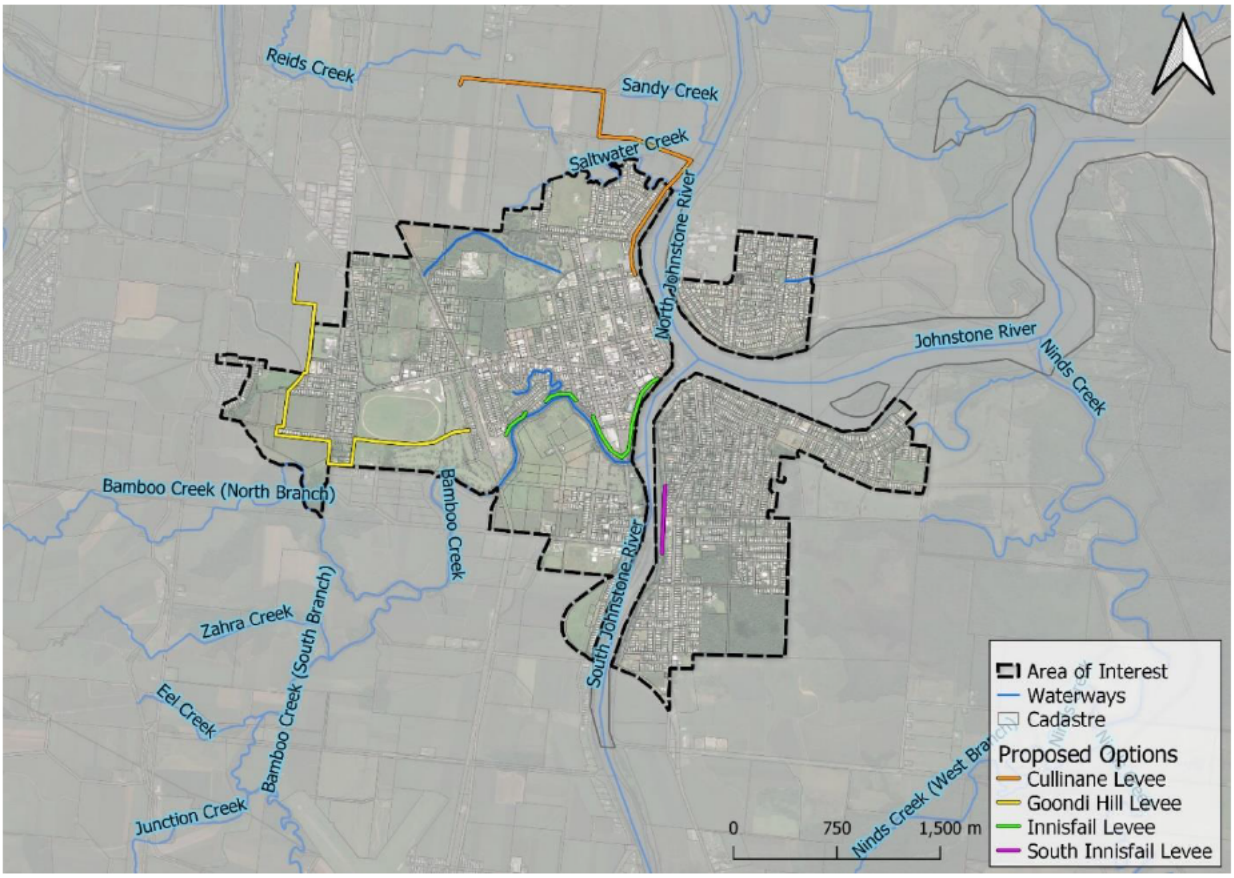

Figure 19. Innisfail mitigation options

4.4 Costing

The mitigation options have been costed based on regional rates and observation of the complexities of the levee location. A summary of the costs is shown in Table 8.

Table 8. Estimated costs for proposed mitigation option for Innisfail.

Mitigation	Description	Cost ($m)
1	South Innisfail	$1.7
2	Goondi Hill Levee	$6.5
3	Innisfail levee	$7.0
4	Cullinane Levee	$6.2
5	Dredging of Johnstone River - Large Scenario	$10.5
	Total	**$31.9**
	Contingency (65%)	**$20.7**
	Total with contingency	**$52.7**

4.5 Current Status

All mitigation options are at a strategic level only stage. They would require studies examining the influence on the broader floodplain.

4.6 Key Considerations and Uncertainties

Previous investigations identified that the mitigation options when applied collectively resulted in increases in flood levels on the floodplain. Unfortunately, these studies did not evaluate the mitigation options individually and the impact of each levee / mitigation option is unknown.

There is a risk that some of these options are not feasible due to the impacts on flood behaviour.

4.7 Summary

Innisfail has significant flood risk and associated potential damage and is a good location to explore flood mitigation options. Some mitigation options have been developed in the past, however these were not examined to find a suitable level of protection to manage the floodplain impacts to the protection offered. There is potential in Innisfail for some mitigation options but a further investigations are required.

Table 9. Innisfail - Summary

Item	Description
Level of Design	Strategic. While the mitigation was assessed in 2014 (with a higher protection), no update to this assessment has been undertaken.
Flood Mitigation Performance	Targeting a 1 in 50 AEP protection for those areas protected by the levees. May be required to lower this protection if negative flood impacts are identified.
Cost Estimate	**$52.7M**
Constraints	• Potential environmental constraints, particularly for the dredging option • Challenges with some levees crossing creeks and roads. Flood gates required • Uncertain on community acceptance of the scheme • Potential flood afflux of the scheme, further investigation required.
Further Work Required	A flood risk management study to undertake appropriate optioneering and community engagement.

5 Rockhampton (QLD)

5.1 Locality

Rockhampton is the largest urban centre in Central Queensland and is located adjacent to the Fitzroy River. The Fitzroy River has a significant catchment of about 140,000 km^2. Rockhampton has been subjected to flooding historically, with typical flood events corresponding to cyclones. Flooding has the capacity to block major north-south transport routes for Queensland as well as restrict access to Rockhampton Airport.

Rockhampton is shown in Figure 20.

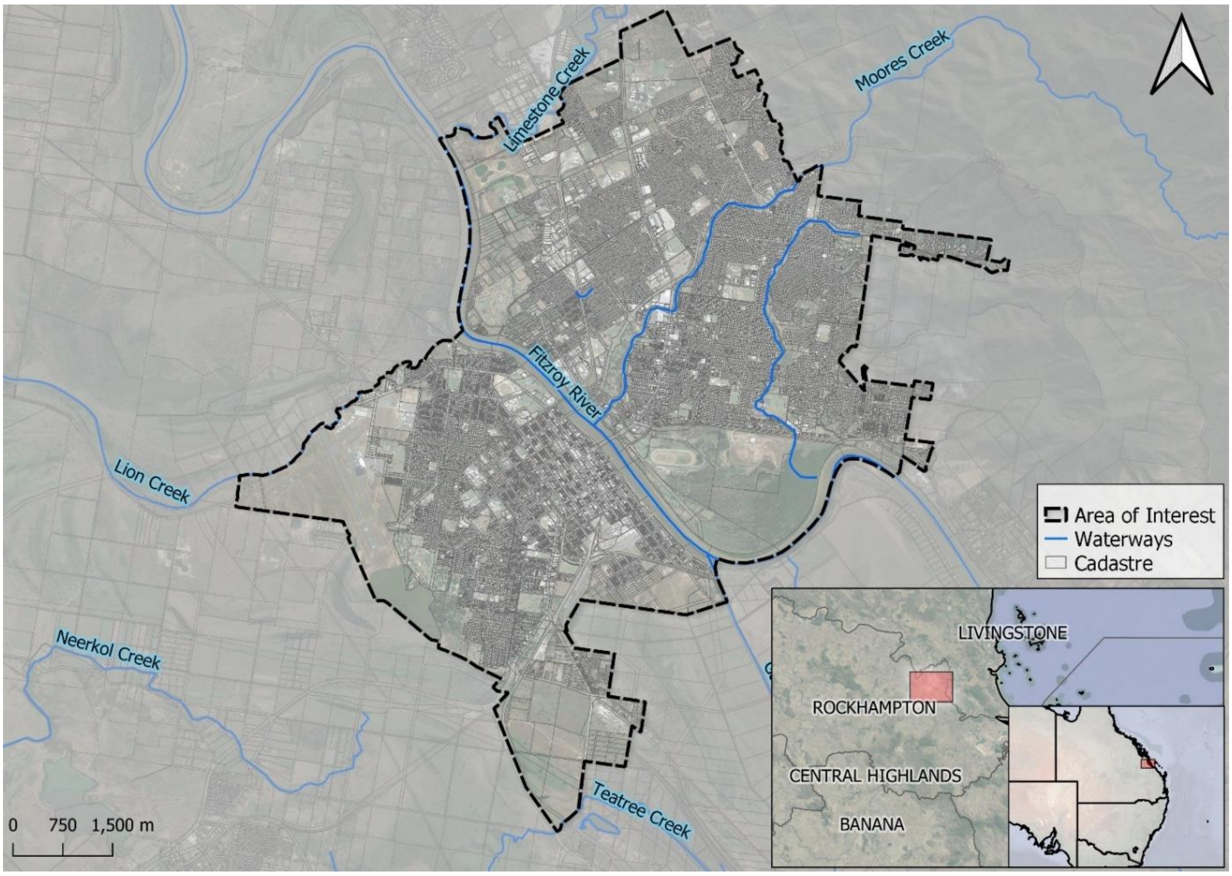

Figure 20. Rockhampton locality

5.2 Flood Behaviour

Rockhampton had serious flooding in 1991 which prompted a detailed investigation into the flooding and potential mitigation for Rockhampton and surrounds. This has since been updated in 2011 and 2014 with revised flood mapping. A summary of the flood investigations include:

- Rockhampton Flood Management Study 1992
- Fitzroy River Flood Study 2011
- Fitzroy River Floodplain and Road Planning Study 2011
- Fitzroy River Flood Modelling 2014.

Historic large floods for Rockhampton include the 1988, 1991, 2008 and 2010/11 floods. Images of the large flood in 1991 are shown in Figure 21, much of the township was inundated. The 2010/11 floods were of a similar level in Rockhampton to the 1991 event.

Fitzroy River looking downstream

Depot Hill Area

Rockhampton Airport

Figure 21. Rockhampton floods in 1991[10]

Figure 22. Rockhampton floods in the 2010/11 floods[11]

The 2010/11 flooding was comparable to the 1991 event and resulted in severe disruption to Rockhampton and the region. Some key impacts included:

- Bruce Highway closure for 13 days

[10] Rockhampton Flood Management Study (Camp Scott Furphy, 1992)
[11] Flood Study Report – Fitzroy River Flood Study (AECOM, 2011)

- Capricorn Highway closure for 13 days
- Airport closed for three weeks.

The type and number of properties impacted are summarised in Table 10.

Table 10. Estimated number of Rockhampton properties impacted in 2010/11 floods

Property Type	No. Affected Properties
Aged care/Nursing homes	16
Agriculture	63
Business	258
Community	161
Industry	338
Livestock	791
Residential	2858
Vacant	826
Total	5311

The impacts to the Bruce and Capricorn Highways interrupt a major transport route for Queensland. Similarly, the impact on the closure of Rockhampton airport for an extended period results in substantial economic impacts. Previous studies have completed damage assessments for the township, however these were not publicly available.

The 1 in 100 AEP flood extent (as generated in 2014 by Aurecon) is shown in Figure 23.

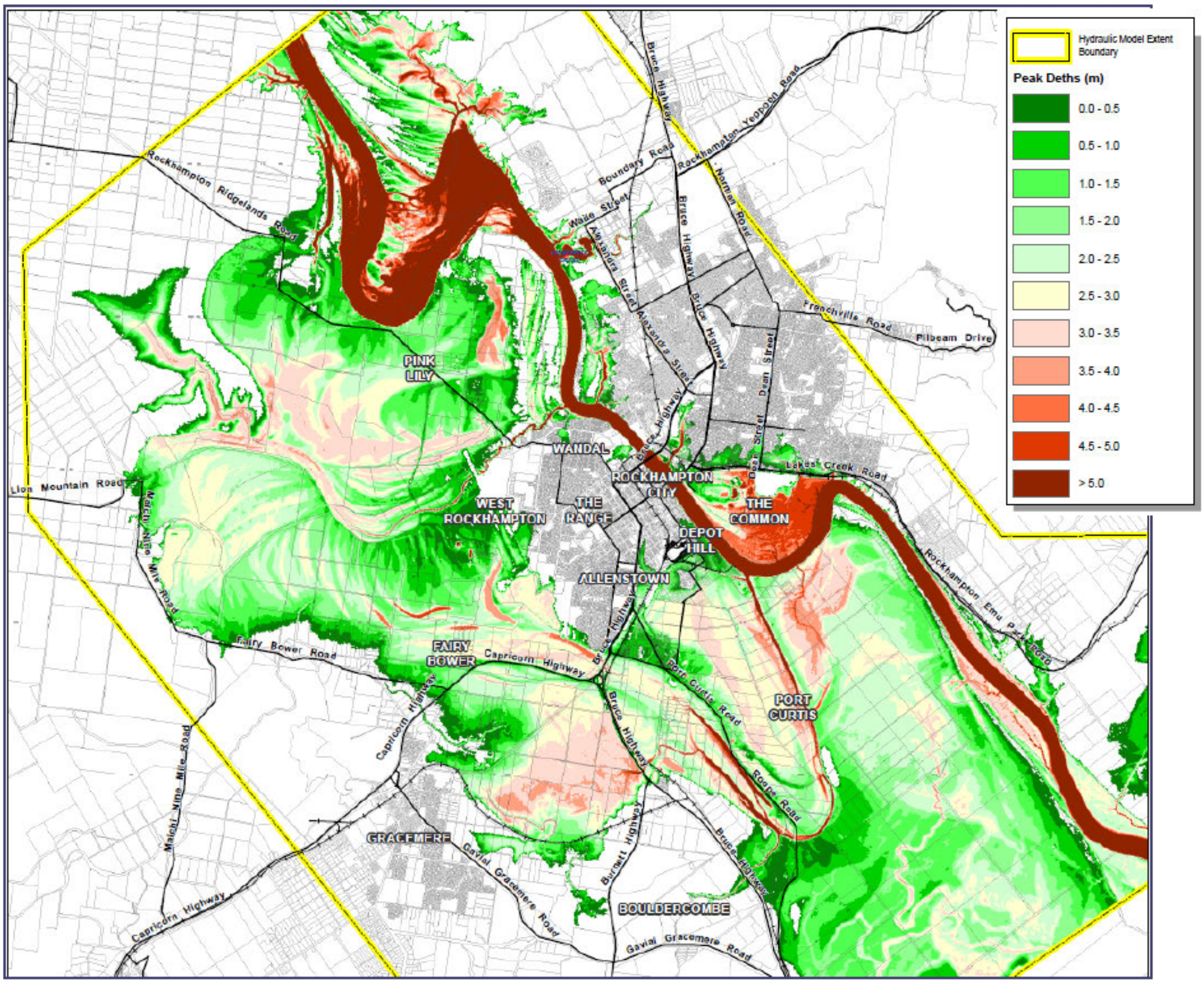

Figure 23. Flood depth for the 1% AEP event at Rockhampton[12]

5.3 Mitigation

A number of studies and investigations have been undertaken in Rockhampton, with a particular focus on the South Rockhampton Levee. This levee is shown in Figure 24 and described in

Table 11. The levee runs to and from the Bruce Highway along the Fitzroy River. The option has been through a detailed Environmental Assessment Report (EAR) process and is ready to proceed to construction.

The key constraint for this project is the lack of funding. It is understood that Council is seeking funding but has yet to receive funding to implement the levee[13].

Given the level of investigation on this mitigation works, this has been focused on in this report. It is also understood that other options are being considered, including raising of the Bruce Highway to improve its flood immunity.

[12] Aurecon, 2014

[13] https://www.rockhamptonregion.qld.gov.au/CouncilServices/Works-in-my-area/South-Rockhampton-Flood-Levee

Table 11. Rockhampton mitigation option description

Mitigation Option	Proposed Protection	General Description
South Rockhampton Levee	1 in 100 AEP	Large levee ~8.8km long, has an EAR completed (2019)

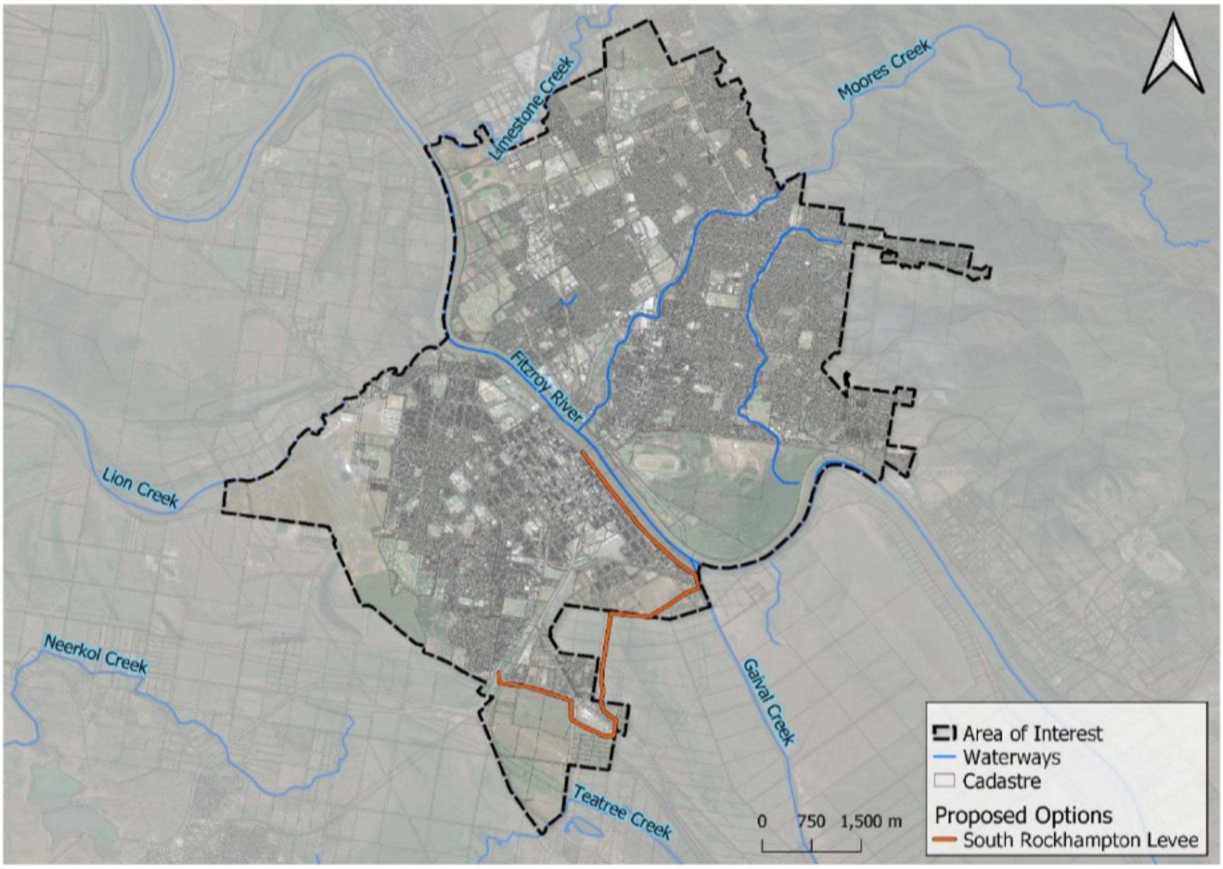

Figure 24. South Rockhampton levee

5.4 Costing

As part of the detailed design process the cost to deliver the project was determined to be $80.4m (AECOM, 2019) (Table 12). This cost estimate includes design, project management and contingencies.

Table 12. Estimated costs for proposed mitigation option for Rockhampton

Mitigation	Description	Cost ($m)
1	South Rockhampton Levee	$80.4
	Total	**$80.4**

5.5 Current Status

The levee has been through a rigorous EAR process and is expected to be ready for construction.

5.6 Key Considerations and Uncertainties

The project has been demonstrated to have a positive cost to benefit ratio and is ready to implement.

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5.7 Summary

There is a significant flood risk at Rockhampton that also has implications for the Queensland economy (by way of the isolation of Rockhampton and the impact on the transport in the region). There are also significant viable mitigation projects that have been developed. Most notably the South Rockhampton The proposed flood levee for the area has had an extensive study already completed (Environmental Assessment Report).

Table 13. Rockhampton - Summary

Item	Description
Level of Design	Detailed design, ready for tender (pending funding).
Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levees.
Cost Estimate	**$80.4M**
Constraints	• Relatively low, given EAR undertaken.
Further Work Required	Minimal, ready to be tendered.

6 South Tweed (NSW)

6.1 Locality

South Tweed is located in the north-east of NSW, south of the Queensland border. As at 2016 South Tweed had a population of 7,615[14]. South Tweed is located on Terranora Creek but is also influenced by flood flows in the Tweed River and coastal inundation (storm surge). There is an existing levee protecting some of South Tweed to around a 1 in 20 AEP level. South Tweed is shown in Figure 25.

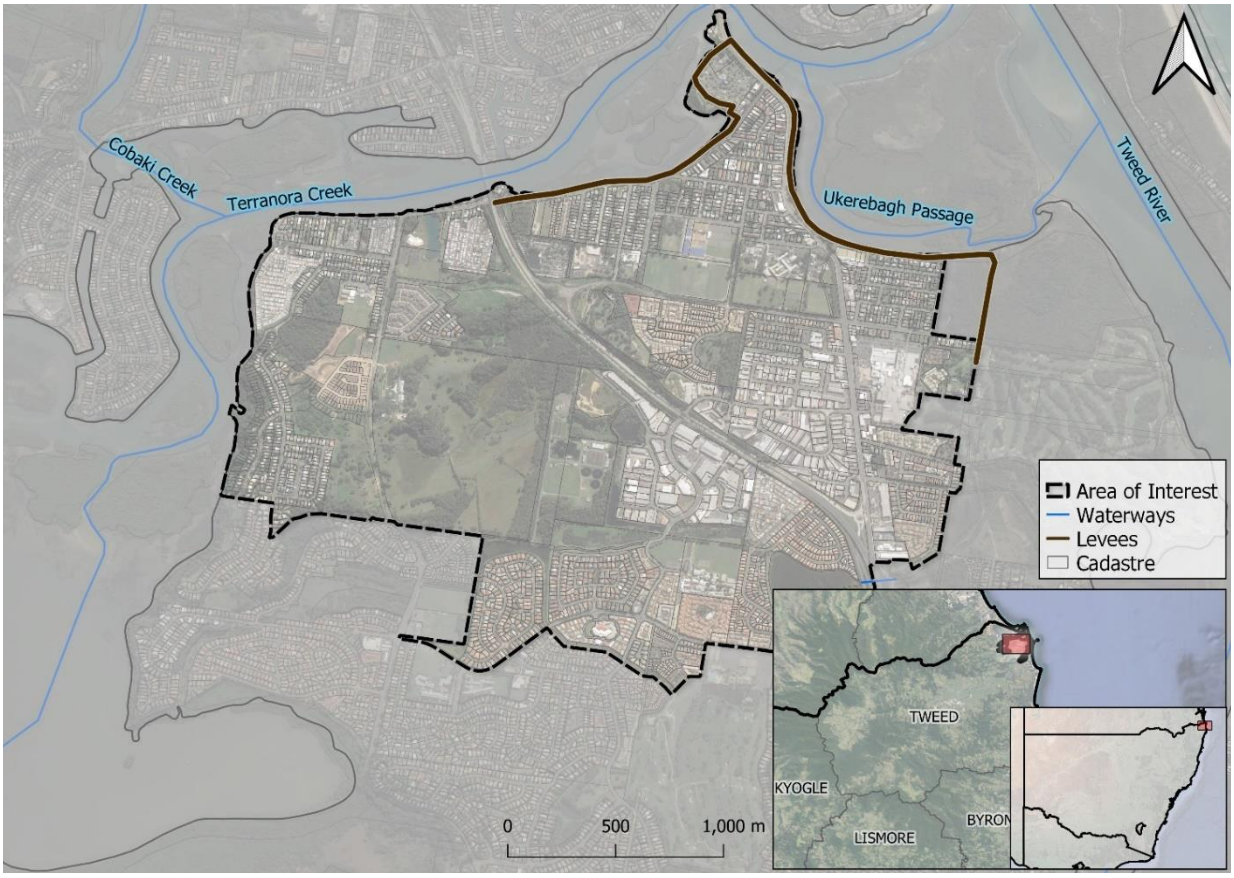

Figure 25. South Tweed Locality

6.2 Flood Behaviour

South Tweed Heads is located between Terranora Creek and Tweed River and is affected by storm surge and tides. There have been a number of major floods in the Tweed catchment in living memory, including the largest flood on record in 1954[15]. In lower Tweed the embankment and drainage structures of the Pacific Highway and Barney Point influence flood behaviour in large events. In extreme events the river mouth / entrance conditions and the dunes between Kingscliff and Fingal Head influence flood behaviour.

Evacuation during flooding in Lower Tweed is extremely constrained. It has limited capacity to safely house evacuees and evacuation routes are limited. Flooding occurs relatively frequently, especially in the older parts of town. Many locations in Lower Tweed flood in events as frequent as the 1 in 20 AEP.

[14] 2016 Census, Australian Bureau of Statistics

[15] Tweed Valley Floodplain Management Study and Plan, BMT WBM 2014b.

Most of the older parts of Tweed Heads South are flooded in a 1 in 100 AEP event, newer development has generally been filled to above the 1 in 100 AEP.

As South Tweed Heads is impacted from frequent flooding, it is currently protected by the Tweed Heads South Levee. Figure 26 shows the 1 in 100 AEP flood extent and the PMF extent across the region. The Tweed Heads South Levee is shown as well, this levee is constructed and provides flood protection to 0.2m below the 1 in 20 AEP event. The Phillip Parade Levee is a proposed levee only and this area currently has no levee protection.

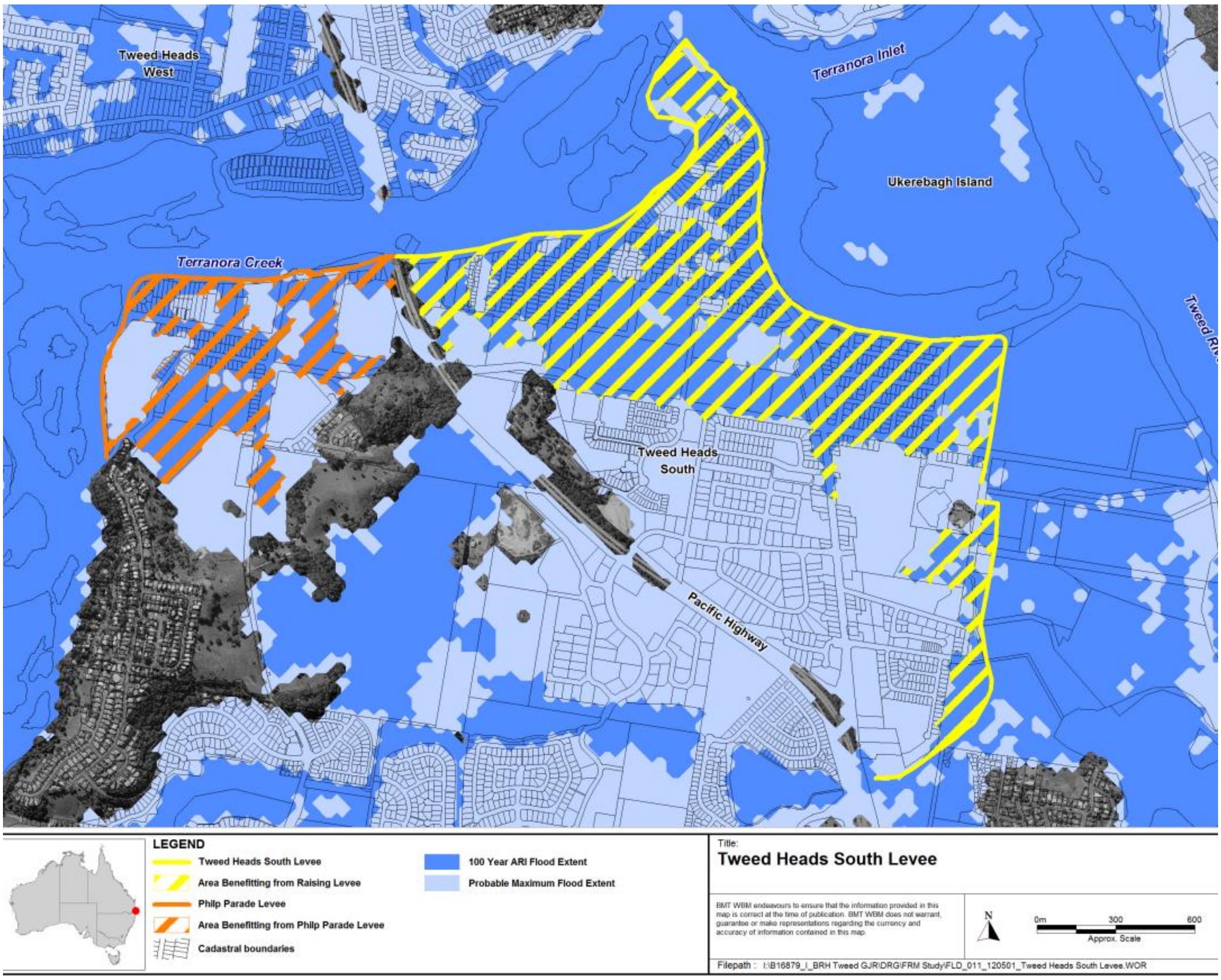

Figure 26. Flood extent for the 1 in 100 AEP and PMF events for Tweed Heads and Levees[16]

[16] Tweed Valley Floodplain Risk Management Study, BMT WBM 2014b.

6.3 Potential Mitigation

A levee around the South Tweed area was investigated at a strategic level as a part of the Tweed Valley Floodplain Risk Management Study in 2014 (BMT WBM, 2014b). The 2014 study identified raising the South Tweed levee around 0.8m to a height of 2.8 mAHD. The levee protects the older parts of Tweed Heads to the east of the Pacific Motorway. Newer development within the existing levee have been filled above the 1 in 100 AEP level. The second option is an extension to the levee along Phillip Parade. This levee would again protect the older parts of Tweed Heads.

A summary of the mitigation options is described in Table 14 and shown in Figure 27.

Table 14. South Tweed mitigation options description

Mitigation Option	Proposed Protection	General Description
South Tweed Levee	1 in 100 AEP	Earth bank, 2 road crossings, Raise from 2mAHD to 2.8mAHD, 4.4km in length
Phillip Parade Ext	1 in 100 AEP	Earth bank, road crossings, one flood gate, build to 2.8mAHD, 1.4km in length

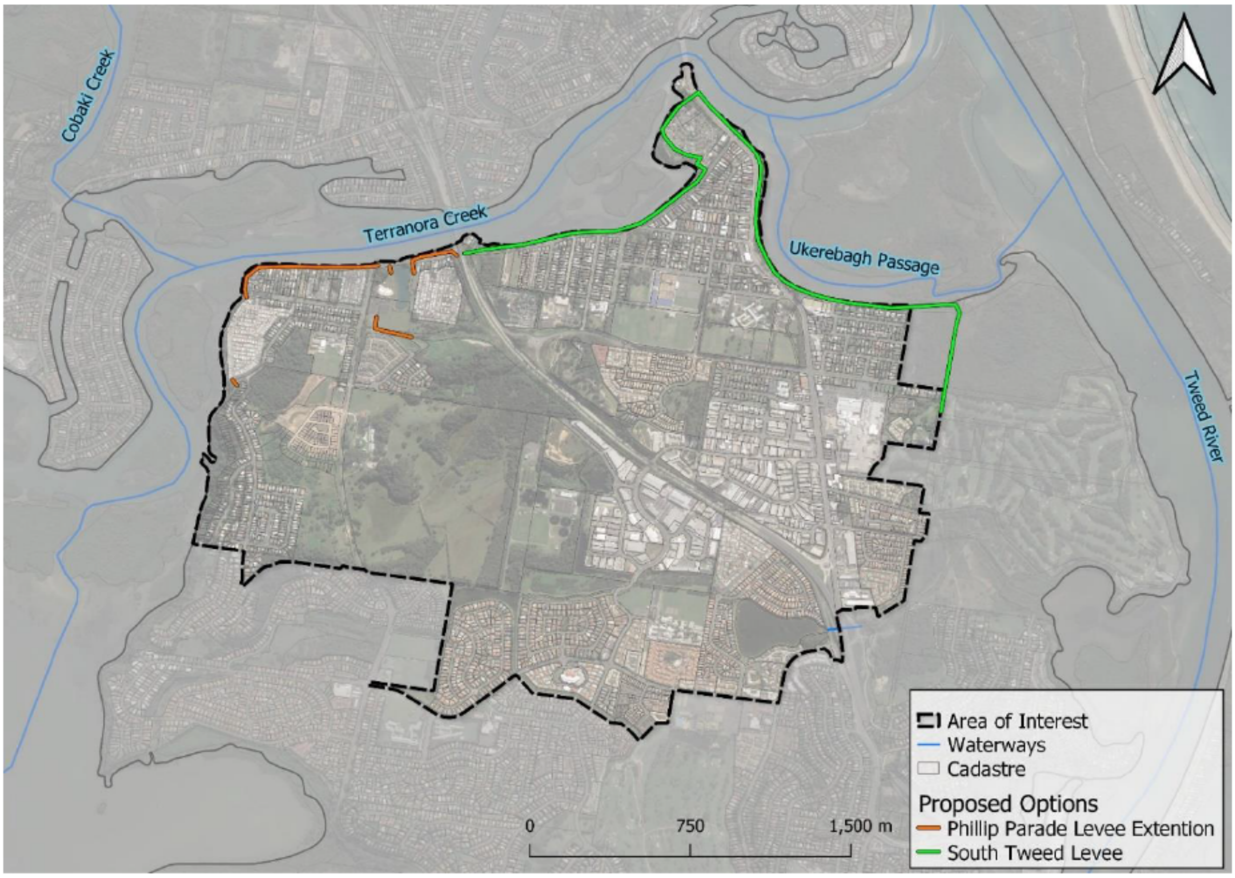

Figure 27. South Tweed proposed mitigation

6.4 Costing

The South Tweed mitigations options have been costed using typical rates for earth levee construction, costs for road crossing and flood gates. The estimates are shown in Table 15.

Table 15. Estimated costs for proposed mitigation options for South Tweed

Mitigation	Description	Cost ($M)
1	South Tweed Levee	$12.1
2	Phillip Parade Ext	$6.6
	Total	**$18.7**
	Contingency (65%)	**$12.2**
	Total with contingency	**$30.9**

6.5 Current Status

Both options have only been investigated at a strategic level as a part of the Tweed Valley Floodplain Risk Management Study (BMT WBM, 2014b).

6.6 Key Considerations and Uncertainties

The South Tweed upgrade has been assessed and is understood to be an option that can progress to concept design stage. It is an existing levee upgrade and the land is available for the works.

The Phillip Parade levee is at concept stage only, this will require an assessment to determine a suitable layout and whether this can achieve the expected protection without impacting the broader floodplain.

6.7 Summary

South Tweed Heads experiences flooding in the older parts of the town in evens below the 1 in 20 AEP event. The existing levee, which was constructed in 1979, protects to around 0.2m below the 1 in 20 AEP event. The levee is currently set at 2mAHD and requires an increase up to 2.8mAHD to protect to the 1 in 100 AEP event with freeboard.

There is also an additional concept option for a new levee along Phillip Parade. This level is a concept only and has not been assessed in greater detail than the current high level study.

It is noted that a higher level may need to be adopted to manage climate change, if the 1 in 100 AEP protection is to be maintained into the future.

Table 16. South Tweed - Summary

Item	Description
Level of Design	Strategic.
Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levee.
Cost Estimate	**$30.9M**
Constraints	• Potential environmental constraints, particularly for Phillip Parade extension • May be further engineering constraints, particularly for the Phillip Parade extension
Further Work Required	A flood risk management study has been undertaken. Further investigation and optioneering required on the levee options.

7 Dalby (QLD)

7.1 Locality

Dalby is located 211 km north west of Brisbane on the Western Downs. Dalby has a population of around 12,000[17] within the town and a further 5,000 residing in the rural district. The town is located on Myall Creek which drains into the River Darling basin. Dalby is the commercial centre for the northern Darling Downs, Queensland's productive wheat region.

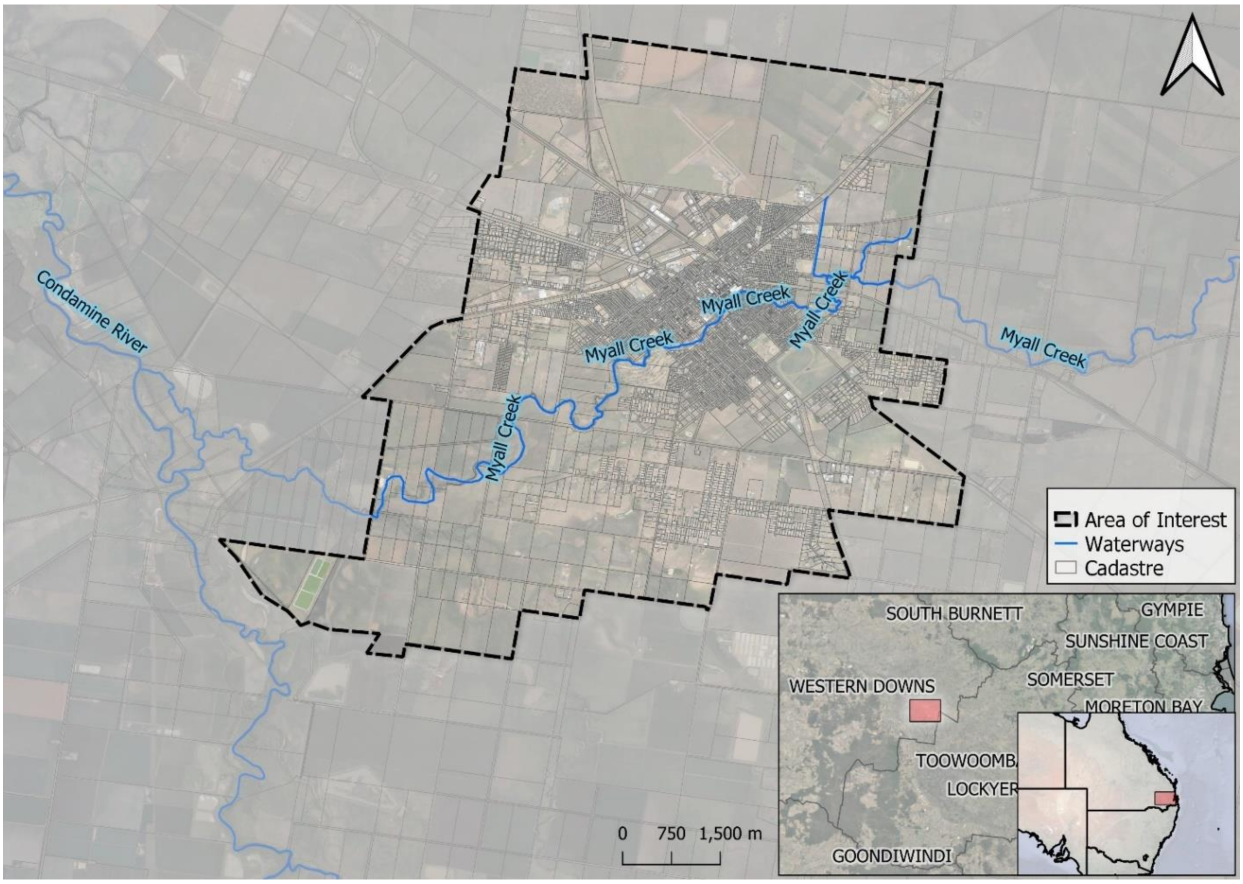

Figure 28. Dalby locality

7.2 Flood Behaviour

Dalby has had a recent flood study completed in 2014 (Water Technology), which updated a previous study (SKM, 2007). As with many other Queensland floods, they are predominantly driven by cyclone events. Several large floods have impacted Dalby, in recent times flooding has occurred in 2010/11 and in 2013[18].

[17] As of 2016, ABS Census

[18] https://queenslandplaces.com.au/dalby#:~:text=There%20have%20been%20seven%20'majormetres%20and%20breaking%20its%20banks

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Figure 29. Dalby flooded in 2010/11 [19]

Figure 30. Dalby flooded in 2010/11 (Picture: Lyndon Mechielsen[20])

The 2014 flood study updated the estimated 1 in 100 AEP flood event as shown in Figure 31.

[19] https://www.couriermail.com.au/news/queensland/sunshine-coast/business/govt-rejects-flood-fund-pleas/news-story/f48cee8f1f8b85f0097716340e9b62ab

[20] https://public.fotki.com/Pedro23/all_sorts_of_travel/around_australia/queensland-floods/queensland-floods/dalby-qld.html

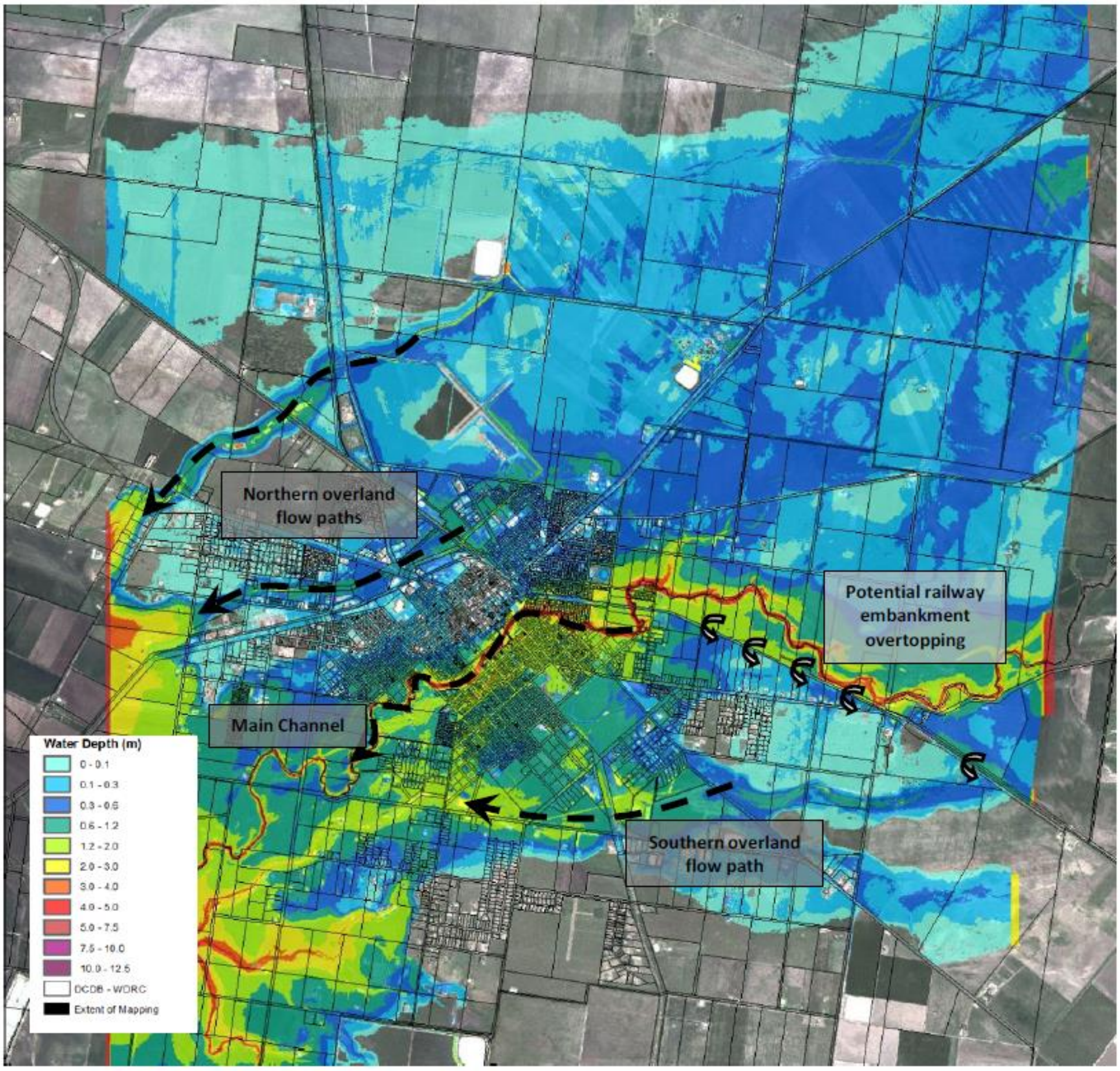

Figure 31. 1% AEP flood depths and extent for Dalby[21]

The IAG residential damage database relies on a single design flood event to assess flood risk in Dalby and therefore has limited ability to simulate the impacts of potential flood mitigation measures. A review was therefore undertaken on the estimation of damages from the Water Technology (2014) study. In the absence of other information, this data has been used to inform the economic assessment.

[21] Dalby Flood Study – Volume 1 – Detailed Technical report, Water Technology 2014

There are an estimated 3,263 properties within the 1% AEP flood extent. A breakdown of the contributing components is summarised in the graphic opposite, with residential properties forming the majority of those likely to experience damage. The full damage costing is shown in Table 18.

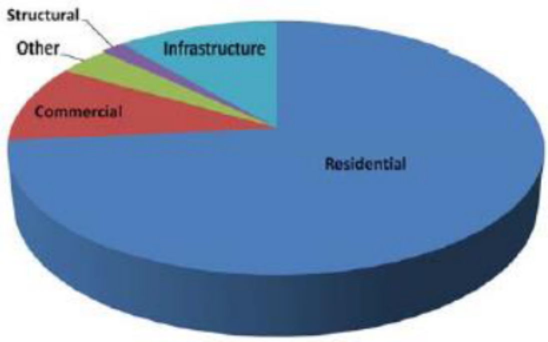

Table 17. Estimated overfloor flooding for Dalby (BMT WBM, 2014)[22]

Inundated Properties (above floor level)		
Event (AEP)	**Residential**	**Commercial/Industrial**
50%	3	0
20%	221	9
10%	847	38
5%	1,347	50
2%	1,868	61
1%	2,118	72
PMF	4,150	227

Table 18. Estimated damages for Dalby (Water Technology, 2014)[39]

Damages ($millions)						
Event (AEP)	**Residential**	**Commercial**	**External / below floor**	**Structural**	**Infrastructure**	**Total**
50%	$0.0	$0.0	$0.0	$0.0	$0.0	**$0.0**
20%	$3.6	$0.5	$0.3	$0.0	$0.6	**$4.9**
10%	$18.1	$2.5	$1.3	$0.0	$2.8	**$24.7**
5%	$33.9	$4.9	$2.1	$0.1	$5.2	**$46.2**
2%	$53.4	$7.5	$2.9	$0.7	$8.2	**$72.7**
1%	$65.6	$9.0	$3.3	$1.4	$10.1	**$89.3**
PMF	$175.9	$43.7	$6.4	$45.4	$34.9	**$306.4**

7.3 Potential Mitigation

Current flood mitigation options have been discussed in the Western Downs Floodplain Risk Management Study - Dalby (Water Technology, 2014) with most investigations limited to small scale measures to address issues associated with stormwater runoff. Some of these mitigation options include the Louis Street Drain and Hospital/Russell Street Drains. However, larger mitigation options have been proposed and assessed at a high level in the 2014 FRMSP for the Darling Downs.

[22] Updated to 2020 dollar terms using CPI adjustment.

The key mitigation options proposed include:

- Northern levee (Ashmore Street levee)
- A southern floodway (flood bypass option).

The northern levee is designed to intercept flow coming from the north at Ashmore Street and direct it into Spring Creek. These flows are broad shallow flows which enter town and approach the airport and town.

Figure 32. Flows overtopping Ashmore Street in the 2010/11 floods (Water Technology , 2014)

A second large-scale option is a southern flow bypass option. This option is more complicated due to the size and scale of the works. There is also substantial land acquisition and road diversion costs that are not yet quantified. It does however have the potential to reduce damages by a considerable amount for the township. The impact on the AAD is not known. For the purposes of the economic assessment, it has been assumed that this scheme has an approximate layout for the southern bypass as shown in Figure 33.

BMT WBM (2014a) considered two alternative floodways, a lower capacity and a higher capacity one. For the purposes of this analysis, the higher capacity one has been adopted. However, depending on budget and constraints, the lower capacity one may be an alternative.

The proposed mitigation options are shown in Figure 34 and described in Table 19.

Table 19. Dalby mitigation options description

Mitigation Option	Proposed Protection	General Description
Levee Ashmore Street	1 in 100 AEP	Earth bank levee, 3 road crossings, 8.8km, ~1-2m in height
Southern Flow Bypass	Unknown	Large bypass, multiple properties impacted. Approximately 1m of earth excavated. Potential alternative lower capacity floodway.

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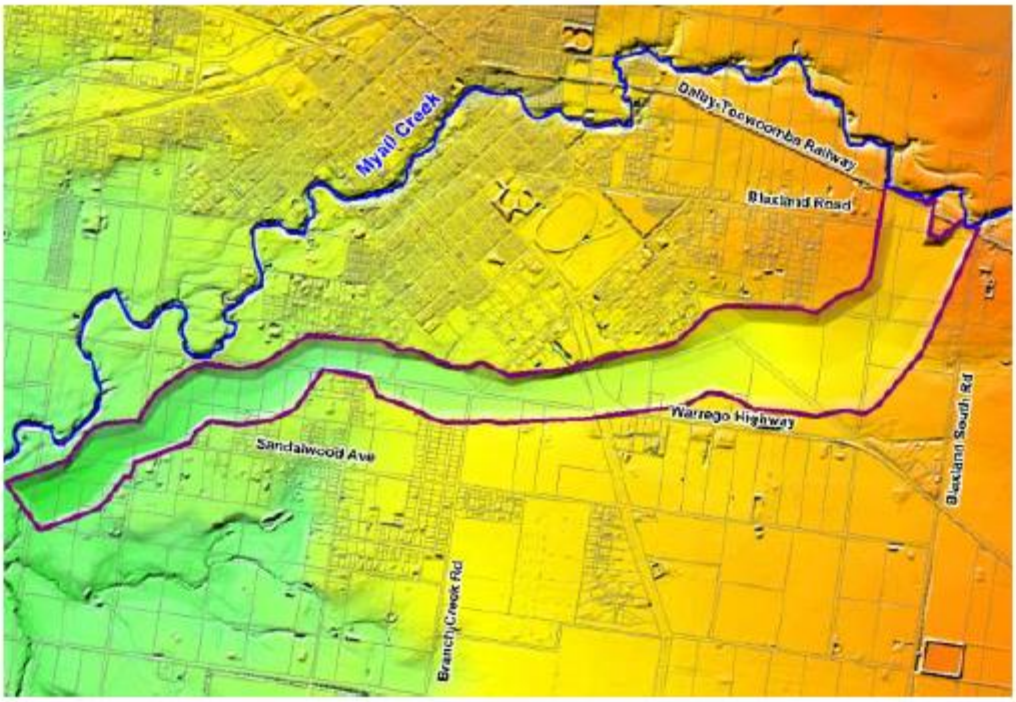

Figure 33. Southern bypass mitigation option (BMT WBM, 2014a)

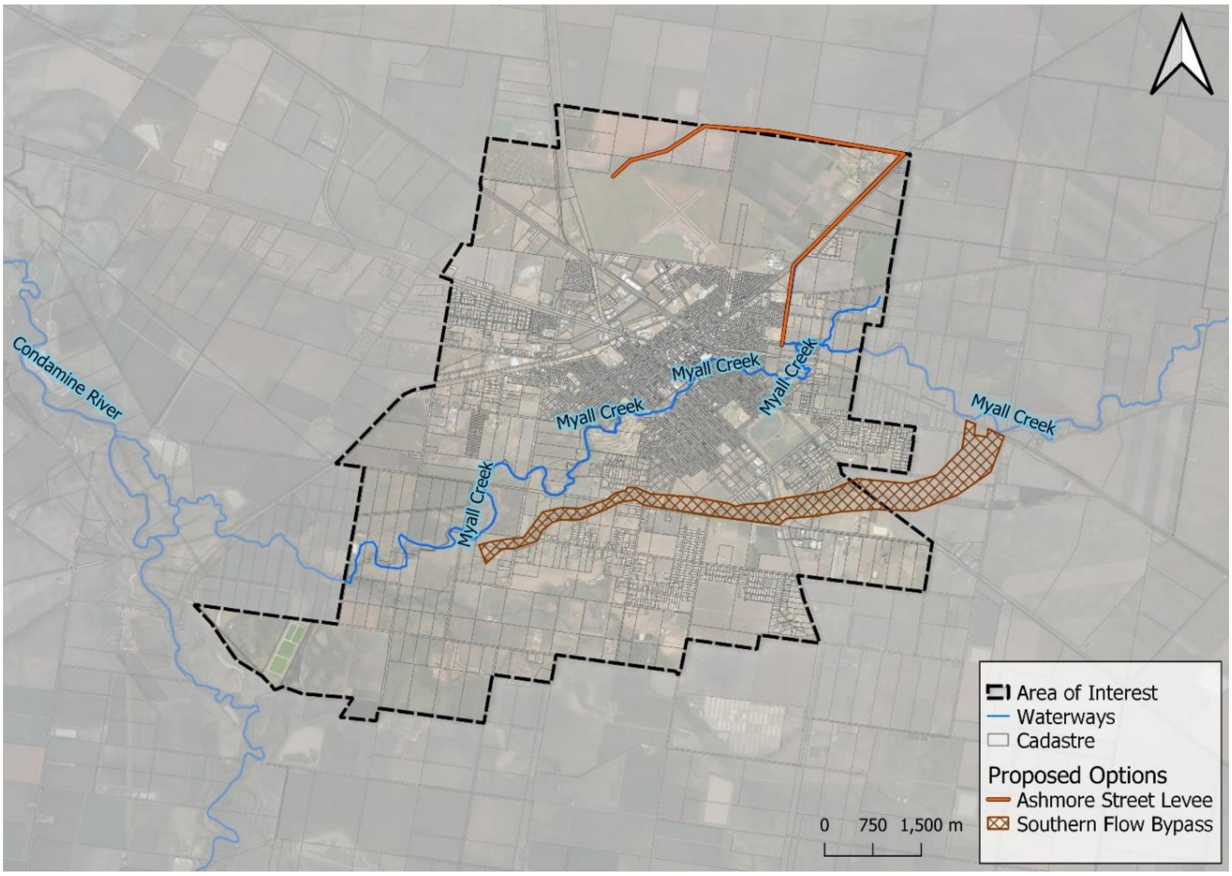

Figure 34. Dalby mitigation options

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7.4 Costing

The levee mitigation option has been costed using assumptions regarding the location and length of the levee and estimated rural levee cost rates. The southern flow bypass option is more difficult to cost given the requirement to use a large section of land to the south of Dalby. This area would require extensive excavation and agreements would be required with owners through this area. A summary of the estimated costs is included in Table 20.

Table 20. Estimated costs for proposed mitigation option for Dalby

Mitigation	Description	Cost ($m)
1	Levee Ashmore Street	$10.8
2	Southern Flow Bypass	$53.9
	Total	**$64.6**
	Contingency (65%)	**$42.0**
	Total with contingency	**$106.7**

7.5 Current Status

The mitigation options for Dalby are at a strategic level only at this stage. No investigation to the viability, benefits and impacts have been assessed.

7.6 Key Considerations and Uncertainties

The mitigation options for Dalby would need further studies undertaken to understand the flood impacts. There is a risk that these options would cause unacceptable flood impacts. For the southern flow bypass floodway there is expected to be considerable risk in getting access and permission to use the land as a bypass.

7.7 Summary

Dalby has significant flood risks that are understood and defined in terms of flood extent, depth of overfloor flooding and damages. A northern levee has previously been identified, with further work required on conceptual design.

A large scale southern flow bypass floodway is possible, but the large size and scale of the bypass may have a number of constraints.

Table 21. Dalby - Summary

Item	Description
Level of Design	Strategic. Further analysis required to understand relative benefits of proposed options
Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levee, uncertain for the flowpath.
Cost Estimate	**$107M**
Constraints	• Potential environmental constraints, particularly for the excavation • Land acquisition issues along the flowpath. • Uncertain on community acceptance of the scheme • Potential flood afflux of the scheme, further investigation required.
Further Work Required	A flood risk management study, to undertake appropriate optioneering and community engagement.

8 Seymour (VIC)

8.1 Locality

Seymour is a historic railway township located at the southern end of the Goulburn Valley in the Shire of Mitchell (Figure 35). Seymour is located 104 km north of Melbourne along the Hume Hwy. Seymour has a population of 6,327[25]. The township services the surrounding agriculture industries of equine, cattle, sheep and wine production. The town also is the main service location for the nearby military base of Puckapunyal (population of 1,176[23]). Seymour is also a regional hub for retail, light engineering, medical services and education.

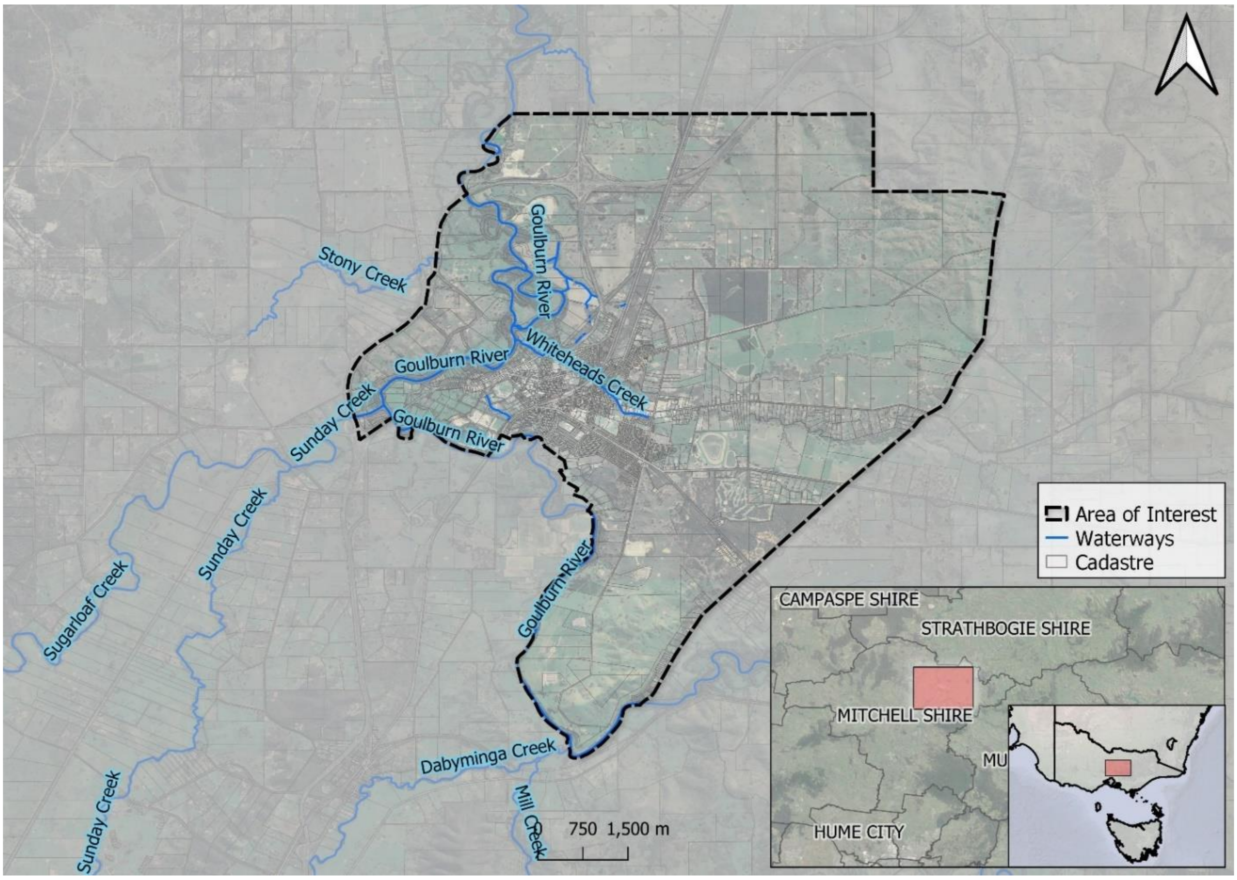

Figure 35. Seymour Locality

8.2 Flood Behaviour

Seymour experiences flooding from the Goulburn River and Whiteheads Creek. Historic flooding occurred in 1870, 1916 and 1917 which forced the relocation of the town commercial centre to Emily Street[24]. The 1916 flood was the largest in the town's history. More recently in 1974 a significant flood inundated the town with one death and nearly 200 buildings suffering direct damage from floodwaters.

The 1 in 100 AEP flood is expected to inundate over 400 buildings with 90% of these having over floor flooding. The 1 in 100 AEP extent based on Goulburn River flooding is shown in Figure 36 (including the proposed levee) and the 1 in 100 AEP flooding for Whiteheads Creek is shown in Figure 37.

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[23] Based on the 2016 census

[24] Seymour Flood Mitigation Project (Cardno, 2015)

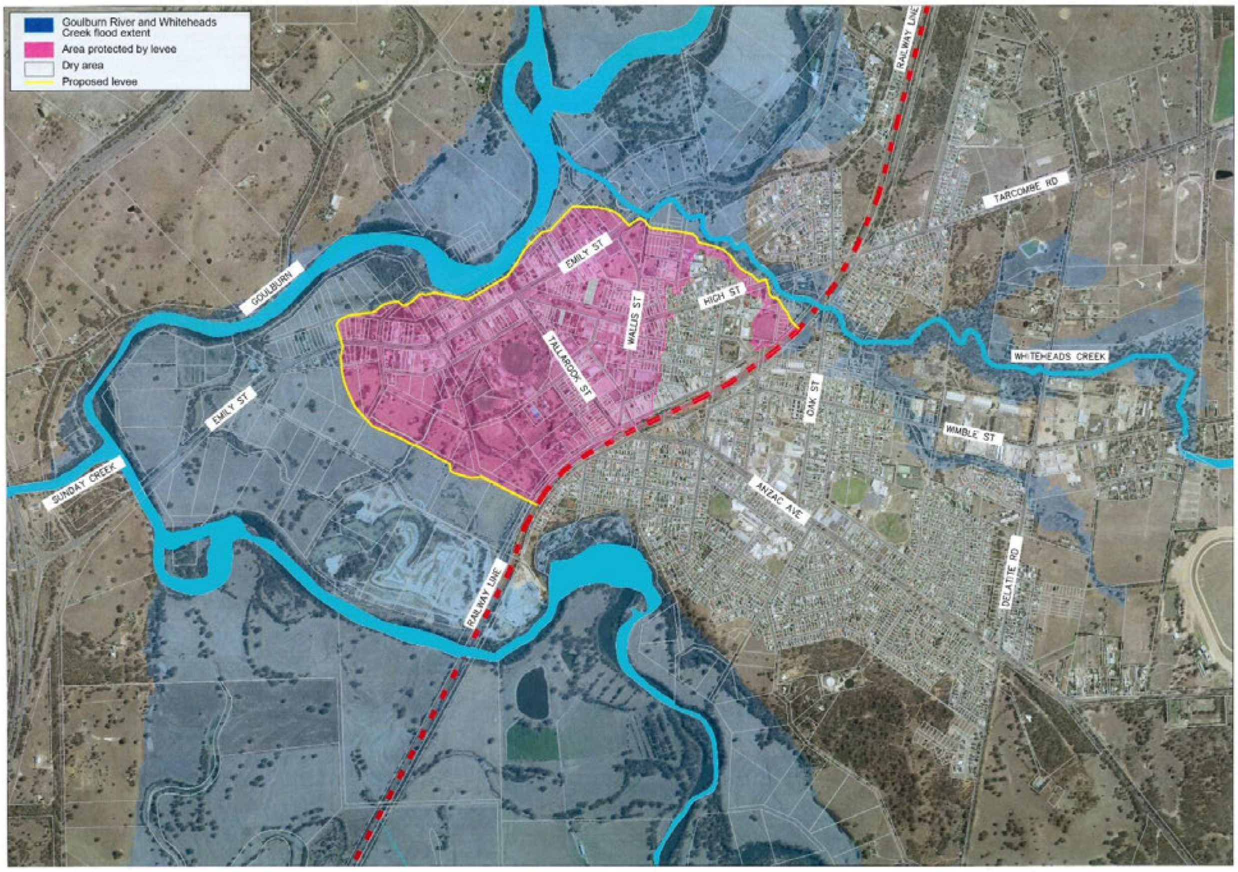

Figure 36. Goulburn River flood extent (with proposed levee), 1 in 100 AEP[25]

[25] https://engagingmitchellshire.com/seymour-flood-levee-2019

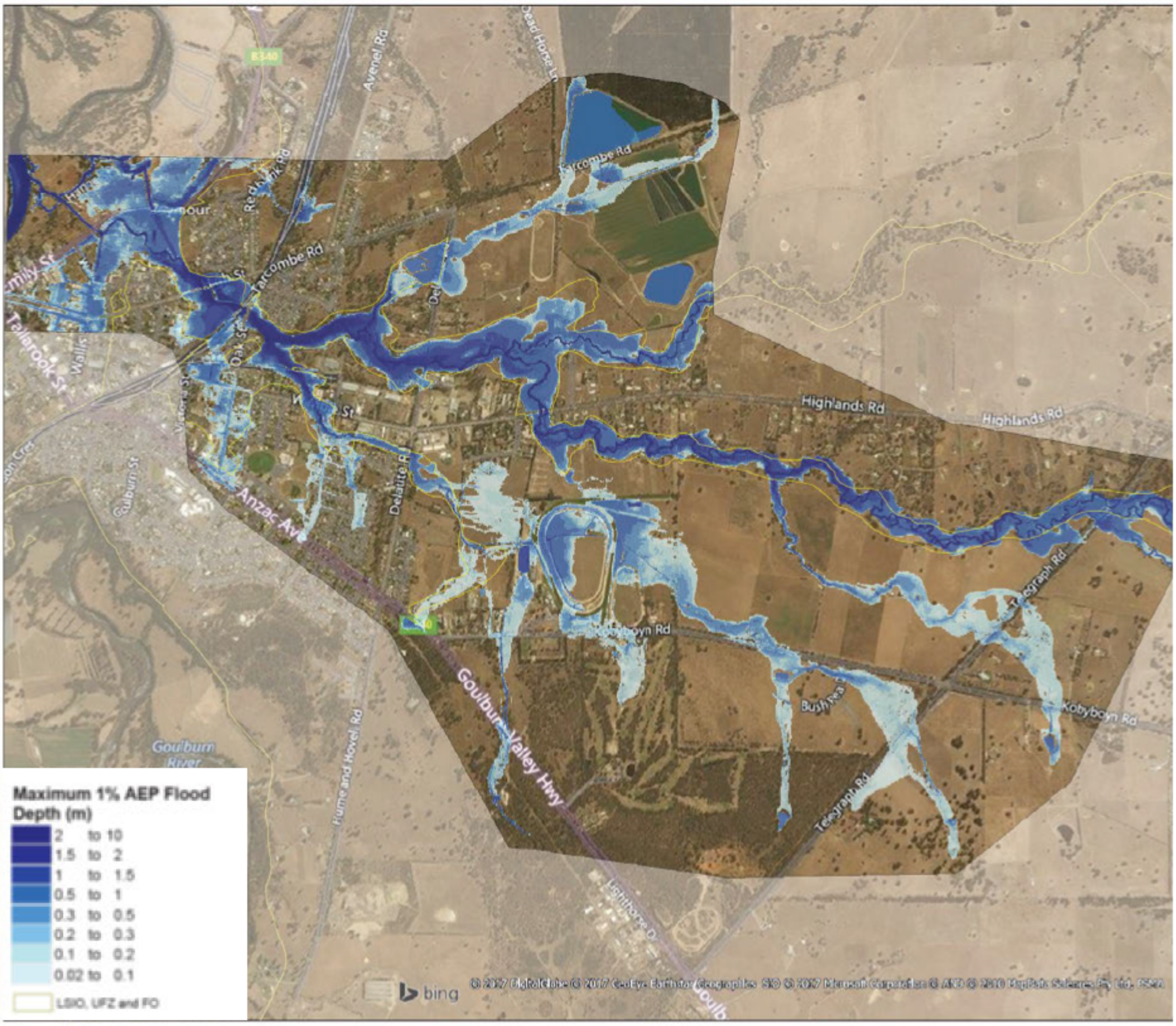

Figure 37. Whiteheads Creek 1% AEP flooding[26]

8.3 Potential Mitigation

The Seymour levee is proposed to protect the main business area of Seymour, the levee has been scoped and designed by Cardno (2015) in the Seymour Flood Mitigation Project. The levee is shown in Figure 38, it includes two major crossings of Emily Street and ties into the existing 1 in 100 AEP protected railway line. Sections of the levee are near buildings and are complex to construct. Major crossings are proposed to be filled using temporary barriers during flooding. A description of the levee is provided in Table 22.

Table 22. Seymour mitigation option description

Mitigation Option	Proposed Protection	General Description
Seymour Levee	1 in 100 AEP	Earth levee with large urban sections, 4.2km long, requires a multiple road crossings.

[26] Source: https://engagingmitchellshire.com/whiteheads

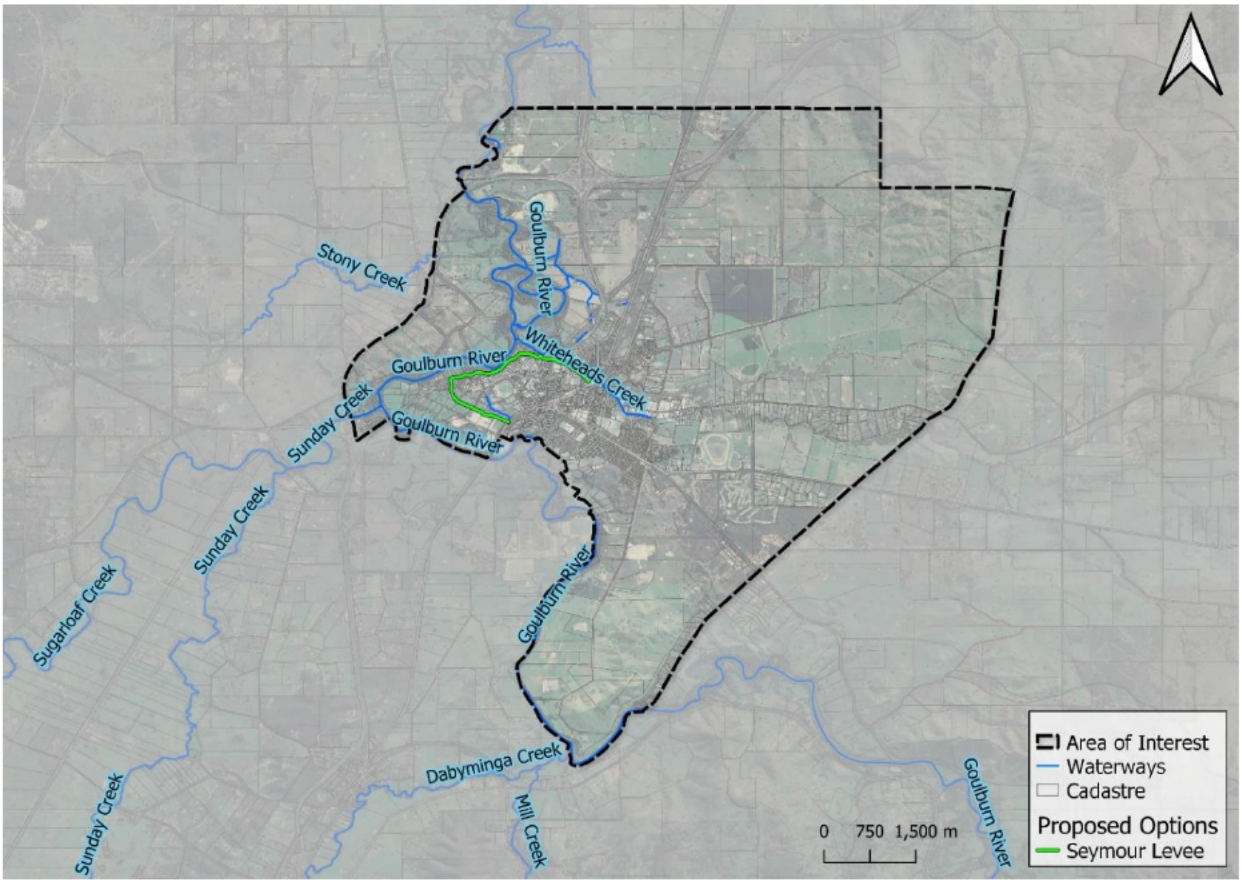

Figure 38. Proposed Seymour levee location

8.4 Costing

The Seymour levee has been fully costed and assessed ready for funding and construction. The project had an estimated cost of $20m and had been through a detailed design process. This cost has been adopted with an additional provision of 25%.

Table 23. Estimated costs for proposed mitigation option for Seymour.

Mitigation	Description	Cost ($M)
1	Seymour Levee	$20.0
	Total	**$20.0**
	Contingency (25%)	**$5.0**
	Total with contingency	**$25.0**

8.5 Current Status

The Seymour levee had been developed through to detailed design. The project was terminated due to community consultation and project funding requirements. The mitigation option is considered to be well scoped and understood.

8.6 Key Considerations and Uncertainties

A Council meeting to consider a future directions report was held on Monday 29 June 2020 where a decision was made to stop the Seymour Flood Mitigation Project. While the proposed Seymour Flood

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Levee was considered to be a 'multi-generational project' aimed at protecting the town's CBD from a 1 in 100 AEP event, the implications and risks associated with the project were too high to warrant further progression[27].

The levee was fully scoped, designed and ready to progress to development, however funding became an issue and the community did not fully support the project and funding approach. Based on discussions with key stakeholders, it is understood that the key issue for the community was the affordability and the cost recovery from the community.

8.7 Summary

Seymour has a mitigation option that can protect the main township of over 400 properties from flooding in the 1 in 100 AEP flood. If funding issues are to be resolved, then the project may receive community support. The mitigation option would be reasonably ready to take to final design.

Table 24. Seymour - Summary

Item	Description
Level of Design	Detailed
Flood Mitigation Performance	Targeting a 1 in 100 AEP protection for those areas protected by the levee.
Cost Estimate	**$25M.** Detailed
Constraints	• Potential community objection, although it is understood that this primarily was associated with the funding rather than the levee itself.
Further Work Required	Finalise detailed design

[27] https://engagingmitchellshire.com/seymour-flood-levee-2019

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Appendix B

Economic Methodology

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1 Introduction

1.1 Overview

The following provides an overview of the economic assessment methodology that has been adopted for this project. It uses a combination of IAG's internal databases for residential damages, together with available literature and guidance on flood damages, and compares these against strategic cost estimates for the mitigation measures identified.

The key purpose of this economic assessment is to:

- Provide an understanding of the level of flood impact within each of the identified study areas;
- Provide a "proof of concept" of the various high level strategic mitigation measures that have been identified for the study areas. While additional work will be required to refine both the cost estimates and the estimation of the benefits, an order of magnitude cost benefit analysis provides an understanding of the potential viability of the potential mitigation works in the study areas.

1.2 Terminology

The economic impacts of flooding a typically estimated through "damages", representing the economic loss at different magnitude flood events.

Benefits from flood mitigation are then typically measured as the reduction in damages that would be achieved as a result of a mitigation measure.

In referring to damages, there are three key categories that are typically referred to:

- Tangible Damages – Direct: these represent the direct cost/impact on the property and building being inundated by floodwaters. For example, the damage to the contents of a house or structural damage to a building.
- Tangible Damages – Indirect: these represent the knock-on costs/impacts as a result of direct damages. They can include relocation/ evacuation costs, loss of wages or sales for a business following a flood etc. These are typically associated with properties that are impacted by flooding. However, properties adjacent to the flooding can also be impacted (for example, a commercial property impacted by a reduction in customers as a result of surrounding flood impacts).
- Intangible Damages: these represent the social and environmental costs beyond those identified above. They can be both direct or indirect and may include mental health issues, risk to life, impacts to the environment and community, etc. They are typically difficult to quantify and estimating their potential reduction as a result of a mitigation measure can be highly challenging.

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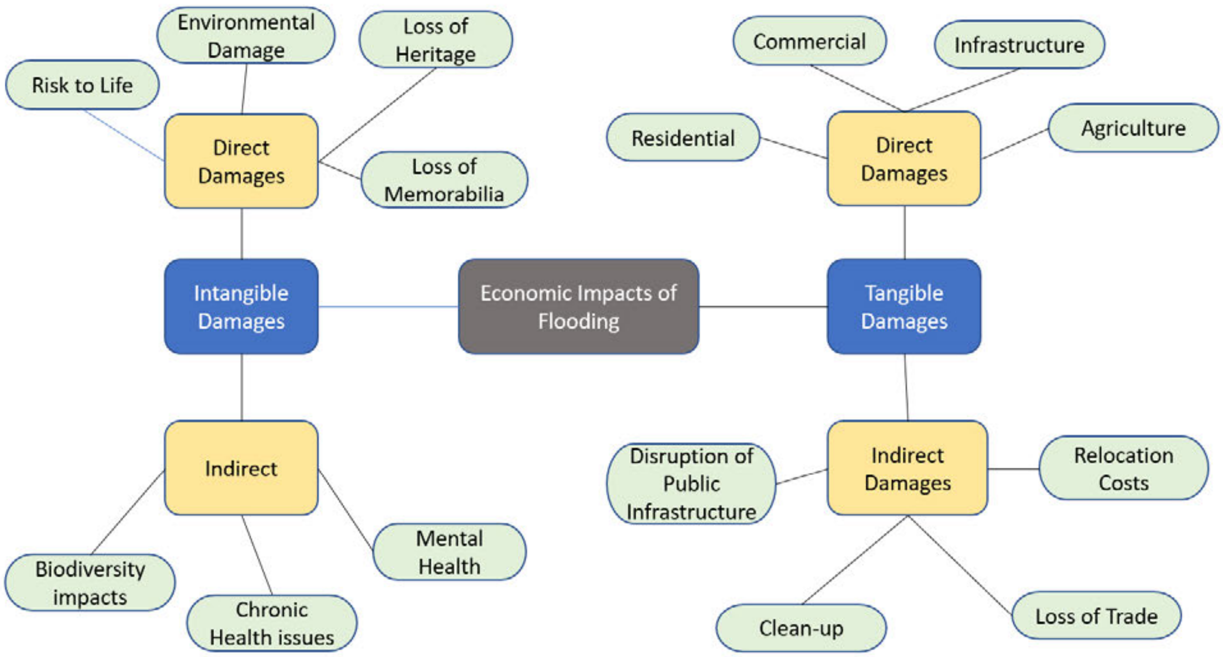

Figure 1. Examples of Types of Damages

1.3 Key Economic Assumptions

The following were the key economic assessment parameters assumed:

- Economic Assessment Period – 30 years. This period commences following construction of the proposed mitigation measure.
- Base year of 2020/21.
- Discount Rate – 7%.

The 7% discount rate is commonly adopted as the core discount rate across most jurisdictions in Australia.

1.4 Approach to Estimating Benefits

Should the mitigation measures identified in this report, or related measures, progress further in their design, then the majority (pending magnitude) would require approval through various government departments, either at a state or Commonwealth level. This would include approval through the different assurance pathways, such as the NSW Treasury gateway process. With this in mind, benefits have been incorporated within this report that are justifiable under that type of framework, and conservative where required.

2 Costs

2.1 Capital Cost Estimates

Capital cost estimates were prepared for each of the potential mitigation measures identified for the short-listed areas. The derivation of these estimates is discussed in **Appendix C**.

2.2 Capital Expenditure Profile

Mitigation measures for each of the study areas are at a different stage of design, with some locations still in an early strategic optioneering phase while others, such as the measures at Rockhampton, have completed detailed design. For simplicity, and to ensure an equal comparison between locations, a simplified expenditure profile over a four year period was assumed. This expenditure profile is shown in Figure 2.

Further refinement of this expenditure profile would be required if the mitigation works are investigated further.

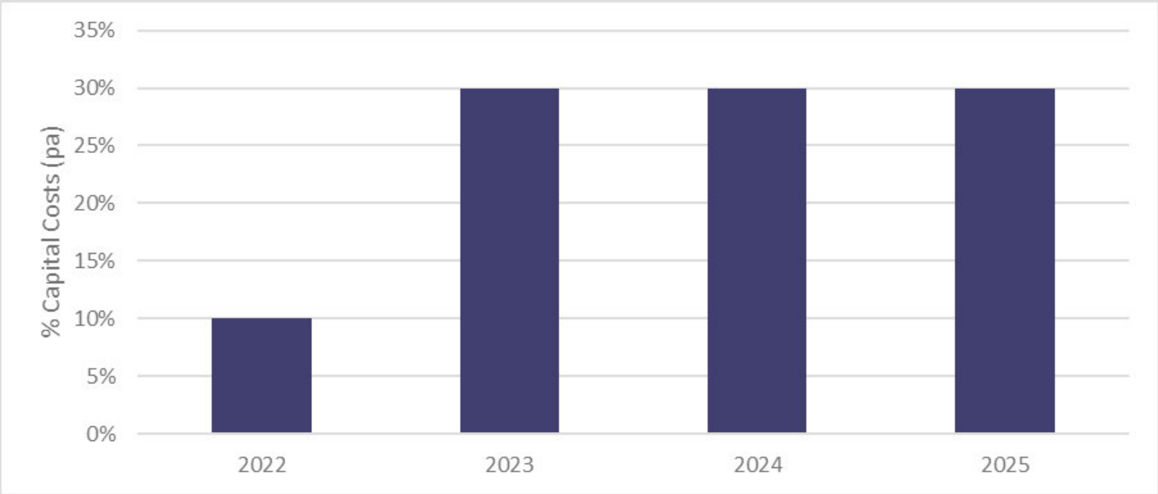

Figure 2. Expenditure Profile Adopted

2.3 Maintenance Costs and Operational Expenditure

The ongoing annual maintenance costs were estimated to be approximately 0.5% of the total capital costs. This was based on cost estimates in AECOM (2019) for the Rockhampton levee project. This also aligns with similar cost estimates that Rhelm has used in other levee projects, and in reviewing levee maintenance costs for various local governments.

2.4 Residual Value

The service life of the infrastructure proposed, where it is properly maintained, will extend beyond the economic assessment period. Therefore, there is a residual value associated with the asset at the end of the economic assessment period.

Based on a number of projects undertaken by Rhelm, the service lives for the key flood options proposed are summarised in Table 1.

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Table 1. Service Life Assumed

Infrastructure	Service Life (yrs)
Levee	70
Floodway	100

3 Tangible Damages

3.1 Residential

IAG provided key summarised information from their damages databases for the study areas, as per Section 2 of the main report. This information was provided at an Australian Bureau of Statistics (ABS) Mesh Block scale.

In addition to direct damages, it is understood that the AAD provided also incorporates indirect damages, such as clean-up and relocation costs.

Given that these estimates are inclusive of both direct and indirect damages, no modifications were undertaken to these estimates for the purposes of this assessment.

It is noted that the loss functions adopted by IAG in deriving these estimates were not provided. The reliability of the AAD estimates are also entirely reliant on the underlying quality of the flood information held by IAG.

3.2 Commercial/ Industrial

While the IAG AAD estimates were provided for residential properties, no equivalent information was available for commercial and industrial damages.

There are a number of stage-damage curves available in the literature to estimates commercial and industrial damages, such as ANUFLOOD, the recent Brisbane River Flood Study (BMT WBM, 2018) and Thomson et al (2021). However, each of these damage curves requires an estimate of a flood level at an individual property, across a range of flood event probabilities. Information at the property scale was not available for this purpose across the study areas.

An alternative approach was adopted by undertaking a review of the correlation between residential damages and commercial damages.

As noted, there are a number of damage curves for both commercial/ industrial as well as residential properties in the literature. For the purposes of this assessment, the Brisbane River Flood Study (BMT WBM, 2018) damage curves were used. This is because these curves are recent, and they are from the same study (and therefore are more consistent).

3.2.1 Comparative Residential Damage Curve

While AAD estimates are available from IAG for the study areas, the loss function for individual properties was not available. In order to undertake a correlation of the residential and commercial damages, a suitable damage curve is required. A representative single storey, slab on ground residential damage curve from the Brisbane River study was adopted for comparison purposes. In addition to the direct damage estimate, the following indirect damages were also included, to be consistent with the IAG residential damages:

- External damages - $15,000 – representative value derived based on the DECC (2007) residential damage curves and Mason et al (2012).
- Clean-up costs - $4000 – this is based on the Smith et al (1990) and BTRE (2002) estimates.
- Relocation costs – derived based on the UK MCM (2013) and adopting Australian rental values.

The resulting damage curve was converted to a total damage per square metre of dwelling.

3.2.2 Commercial Damage Curves

Direct Damages

The Brisbane River Flood Study (BMT WBM, 2018) commercial damage curves are based on the ANUFLOOD damage curves (and updated based on surveys in Brisbane) and include five "value classes" representing different types of commercial and industrial uses, as well as different sizes of commercial premises (small, medium and large). For the purposes of this assessment, the medium sized commercial damage curves were used.

A key challenge with any of the commercial and industrial damage curves in the literature is the significant variability in the underlying estimates, which is a function of the variation in commercial and industrial uses. Not only can this vary between locations, but also over time as commercial tenancies change. Figure 3 shows the range in commercial damage estimates based on the Brisbane River Flood Study, providing an overview of the potential variability.

Indirect Damages

Indirect commercial damages can include loss of sales and rent, as well as clean-up costs following a flood event. However, it is important to recognise the difference between financial and economic losses and ensure that transfer payments are not included. For example, while an individual shop has lost sales during the recovery after the flood event, a shop in a neighbouring town is likely to have increased sales as a result, and therefore the net impact on the economy is not the loss of sales only.

In the Australian-based literature, the typical approach adopted has been to incorporate a percentage of the direct damages, rather than attempt to estimate the indirect damages, for example:

- BMT (2018) undertook a review of some of the relevant guidance on indirect damages for application to the Brisbane River Flood Study. BMT (2018) adopted a rate of 55% of the direct damages for commercial properties. This was based on guidance from DNRM (2002), although it is not clear the underlying assumptions.
- Read Sturgess and Associates (2000), as part of the Rapid Appraisal Method (RAM) recommends adopting 30% of the direct damage as an estimate.

In recent work undertaken by Rhelm (and reported in Thomson et al, 2021), the loss of trade was estimated based on data on business closures and impacts is available from the Queensland floods of December 2010 and January 2011. A survey of 555 businesses undertaken by the Chamber of Commerce & Industry Queensland (2011) identified periods of business closure and direct damages. The survey was undertaken between 18 January 2011 and 25 January 2011 and was therefore still soon after some of the flood events (the Brisbane River flood, for example, was roughly a week before, and 34% of the respondents were from Brisbane). The estimated indirect damages associated with lost earnings are provided in Table 2, with the median around 18% of the indirect damages. Allowing for clean-up costs, a 30% value for indirect damages (as per Read Sturgess and Associates, 2000) may be representative. Therefore, this has been adopted for this study.

Table 2. Estimate of Indirect Damages based on Queensland Flood Business Survey[1]

Statistic	Direct Damage	Indirect Damage – Estimated Total Lost Earnings		
		Financial	Economic	% of Direct
Median	$40,000	$70,000	$7,000	18%
Average	$588,689	$908,087	$90,809	15%

3.2.3 Correlation of Residential and Commercial Damages

Based on the above analysis, a comparison was undertaken between the total damages per square metre (inclusive of both direct and indirect damages) of both the residential and commercial damages, as shown in Figure 3.

This comparison shows a reasonable degree of similarity between the residential damages and the commercial damages for a Value Class 3, which is around the middle of the range for commercial properties.

On this basis, the residential total damage per square metre may provide an approximation of the average commercial damages per square metre, noting that there is a large degree of variability in the underlying commercial damages between the value classes.

Therefore, for the purposes of this strategic level assessment, it has been assumed that the IAG AAD per square metres provides a reasonable approximation for the commercial damages per square metre.

[1] Economic costs estimated in accordance with the UK MCM, adopting 10% of the financial cost.

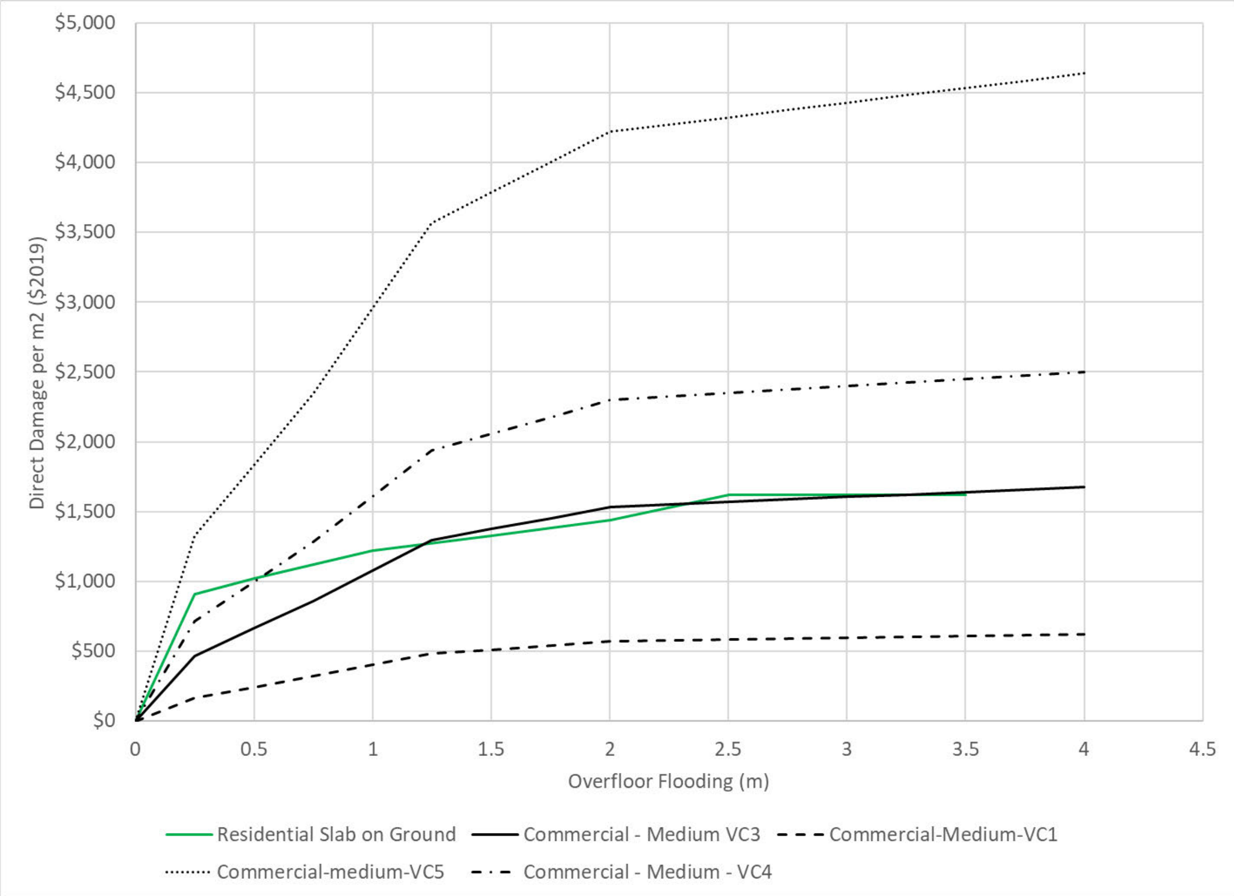

Figure 3. Comparison of Commercial and Residential Damage Curves[2]

3.2.4 Estimate of Commercial Damage per Mesh Block

In order to estimate the commercial damages for each mesh block within a study area, the following was undertaken:

1. Convert the total annual residential damages for a mesh block to an average AAD per square metre. This was based on the number of dwellings, and assuming an average dwelling size[3] of 220m². Given the correlation above, it was assumed that the AAD per square metre for residential would be similar to the AAD per square metre for commercial properties.
2. Estimate the commercial and industrial building footprint areas for each mesh block. This was estimated using Microsoft building footprint data for Australia[4], and overlaying land use planning data for the various jurisdictions. This resulted in a total building square metre for the mesh block. It is noted that this does not consider buildings that are more than one storey, and merely assesses the ground floor or building footprint. However, as most of the damages are typically on the ground floor, this was considered a reasonable approximation.

[2] VC = Value Class
[3] Based on the ABS 8752.0 - Building Activity, Australia, Dec 2018 for new builds (detached homes)
[4]https://github.com/microsoft/AustraliaBuildingFootprints

3. Using the total commercial and industrial building footprint area, together with the AAD per square metre from Step 1, an estimate could then be made on the commercial and industrial AAD.

This approach assumes that the damages per square metre on a mesh block scale are reasonable uniform. Either the residential and commercial properties are spread evenly throughout the mesh block, or that the flood levels are reasonably consistent across the mesh block. Given the small scale of the mesh blocks, this is considered to be appropriate for this strategic assessment.

3.2.5 Considerations

Key considerations in this analysis are:

- There is a large potential variability in commercial and industrial damages, which is dependent on the type of commercial and industrial use. The approach adopted effectively uses a value class that lies largely in the middle range. However, areas with higher or lower value commercial uses could result in changes in the flood damage estimates.
- The conversion approach between residential and commercial damages provides a strategic level estimate of commercial damages. However, for more detailed assessments, it is recommended that a more detailed review of commercial buildings and their potential flood damage be completed.

3.3 Infrastructure Damage

Infrastructure flood damage includes damage to public infrastructure such as roads, bridges and utilities (water, electricity etc), as well as parks and other recreation areas.

Some methods, such as the RAM (Read Sturgess & Assoc, 2000), rely on explicit estimates of the damages based on, for example, a damage per kilometre of road inundated. However, these estimates require a detailed understanding of the flood extents and depths across a range of flood events.

An alternative approach is to adopt an uplift factor, based on the total damages to residential buildings. This is largely on the basis that the proportion of public infrastructure is somewhat proportional to the total number of dwellings in an area.

Based on assessments of the 2000 and 2007 floods in the UK, Penning-Rowsell et al (2013) estimated the breakdown of damages as provided in Table 3. However, Penning-Rowsell et al (2013) also noted that these two floods were relatively severe in the UK, and that the proportion of damage to public infrastructure could be highly variable.

For this project, a 25% of residential damages has been adopted as representative of the likely infrastructure damages. Based on the values in Table 3, this would appear to provide a reasonable estimate of the potential damages to the various elements of public infrastructure.

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Table 3. Damages sustained during the UK 2000 and 2007 floods and those damages as a percentage of total household damages and total household and business damages (Penning-Rowsell et al, 2013)

	Damage Estimate (£ million)	% as a proportion of total household damage	% as a proportion of total household and business damage
2000 floods			
Property Damages	570	-	-
Road Traffic Disruption	13	2.3	-
Railway Network	6	6	-
2007 floods			
Households	1200	-	-
Businesses (buildings, contents & disruption)	740	-	-
Electricity	138	11.5	7.1
Gas	<1	0.1	0.1
Water (and wastewater)	186	15.5	9.6
Roads	191	15.9	9.8
Rail	36	3	1.9
Telecommunications	<1	0.1	0.1
Schools	49	4.1	2.5

3.4 Clean-up Costs

While both the commercial and residential damages incorporate an allowance for clean-up, this focuses on the individual properties, and not to public spaces and public infrastructure. In the March 2021 Hawkesbury-Nepean flood, in addition to significant clean-up of individual properties, significant debris was washed down the river system and large amounts of that debris accumulated along the foreshore in specific locations as well as out to the ocean before being deposited on beaches and was required to be cleaned up by various councils. Hawkesbury City Council reported around 4,700 tonnes from March to July 2021 of flood debris clean-up, although this was focused more on affected residential dwellings[5]. Central Coast Council identified that 710 tonnes of flood related debris were cleaned off beaches in their LGA following the Hawkesbury River flood[6].

With increasing costs of disposal, together with the potential contamination of this material (including from asbestos) the disposal costs can be relatively high, together with the effort required for the clean-up itself.

In 2011, the Brisbane River flood resulted in significant mud and silt being deposited that was cleaned up by volunteers and public authorities. Estimates from that flood were that the clean-up and

5 https://www.hawkesbury.nsw.gov.au/_resources/media-releases/2021/july/free-skip-bin-service-for-flood-waste-concludes

6 Central Coast Ordinary Meeting Minutes, 27 April 2021, https://cdn.centralcoast.nsw.gov.au/sites/default/files/Council/Meetings_and_minutes/amendeditem59centralcoastcouncilfloodrecoveryreport.pdf

rehabilitation of public assets and spaces was roughly 4% of the total damages of the flood (BMT WBM, 2018).

For the purposes of this project, a similar 4% has been assumed. This 4% has been applied to the total residential and commercial damages.

Figure 4. Mud in Brisbane in 2011 Flood[7] (Left) and Clean-up of Patonga Beach after Hawkesbury 2021 Flood[8]

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[7] flickr.com/photos/brisbanecitycouncil/5429354413

[8] NBN News (2021). *Hawkesbury River Rubbish – Two Tonnes Collected from Patonga Beach. nbnnews.com.au/2021/03/25/hawkesbury-river-rubbish-two-tonnes-collected-from-patonga-coastline/*

4 Intangible Damages

4.1 Introduction

Intangible damages incorporate impacts to individuals and the overall community that typically do not have a market or dollar value. For example, these may include flood-induced anxiety, depression and/or post-traumatic stress disorder (PTSD), living disruptions and loss of community. There are a variety of economic methods that can be used to estimate the monetary value of some of these impacts, such as Willingness to Pay methodologies. However, these are typically only undertaken in very large projects. In other cases, these methods are used to derive reference values that can be adapted for wider use. Due to the nature of intangible damages, it is difficult to estimate them to a high degree of accuracy.

Where intangibles are incorporated within an assessment, one of the most common ways this is done is through an uplift factor, where the intangibles are estimated as a proportion of the tangible damages.

The studies undertaken by Deloitte (2016) suggests that the average intangible-to-tangible ratio is 1.2. However, it is noted that this is based on three separate types of disaster (earthquake, fire and flood), and all of which were relatively large in scale for Australia (e.g., Brisbane flood).

Deloitte (2021) updated this analysis to estimate the proportion of intangible damages. This was based on an analysis of three historical events:

- The South-east Queensland floods (Queensland, 2010–11)
- The Black Saturday bushfires (Victoria, 2009)
- The 'Pasha Bulker Storm', an East Coast Low event (Newcastle, New South Wales, 2007).

In the revised estimate, they incorporated a reduction in the multiplier for smaller (or more frequent events). While not explicitly reported, a review of the results would suggest that the intangible damages are roughly 75% of the tangible damages.

BMT WBM (2018) for the Brisbane River Flood Study reviewed the Deloitte (2016) analysis and incorporated an adjustment to the intangible damage uplift factor. This adjustment was based on an analysis of indirect damages from flooding in Katherine (Northern Territory) and assumed that intangible damages would follow a similar trend to indirect damages. The proposed BMT WBM (2018) uplift factors are summarised in Table 4. For the Brisbane River Flood Study, these factors resulted in intangibles being approximately 55% of the tangible damages. However, this uplift would vary from floodplain to floodplain, given the variability in the values in Table 4.

For the IAG residential database, individual damages for different events were not available, and only a summarised AAD value. However, the number of dwellings impacted for each AEP range can be estimated based on the information provided. This can be used to estimate an approximate intangibles uplift factor for the AAD.

Table 4. Uplift Factors for Intangibles as identified in BMT WBM (2018)

AEP	Intangibles uplift factor
5%	0.00
2%	0.72
1%	1.20
PMF	4.56

The purpose of the Deloitte (2021) study was to provide an estimate of the total damage of natural disasters in Australia at a macro scale. However, applying an uplift factor of 75% may be difficult to justify when assessing the viability of a specific infrastructure project for approved funding.

An alternative approach is to estimate the intangible values more explicitly. In this study, this has been undertaken in two ways:

- Estimating the Risk to Life (Section 4.2)
- Estimating other Intangibles from Willingness to Pay studies in the literature (Section 4.3).

4.2 Risk to Life

One component of intangible damages relates to the potential loss of life and injury for people as a result of the flood.

Risk to life, or more correctly, estimating the value of the loss of life in a flood, requires two key components:

- An estimated Value of a Statistical Life (VSL), representing the economic value of a typical person
- An estimate of the likely loss of life in a floodplain in any given flood event.

4.2.1 Value of a Statistical Life

Transport for NSW (2020) provides a detailed review of the available literature for VSL and based on this review they adopted Willingness to Pay values to void casualties and fatalities associated with transport related accidents. These are summarised in Table 5. These are recommended for use in all Transport for NSW economic assessments.

In the absence of more detailed assessments in the flood sector, these are likely to represent the best estimates for Australian conditions.

Table 5. Cost per Casualty (TfNSW, 2020)

Source	VSL (2019 AUD)
Fatality	$7,752,786
Serious Injury (requiring hospitalisation)	$495,874
Moderate (emergency department) or minor injury	$77,472

4.2.2 Probability of Loss of Life

The probability of loss of life/injury occurring varies in terms of:

- The likelihood, magnitude and nature of the flood event
- The characteristics of population at risk, including amongst others:
    - Number of individuals
    - Demographics
    - Flood awareness and education
    - Accessibility and evacuation planning.

WRL (2016) undertook a literature review of loss of life estimation methods. These are primarily divided into empirical methods and agent-based modelling, with the empirical methods having the largest literature base. A detailed review of the different methods is provided in WRL (2016).

WRL (2016) found that the different methods tended to result in relatively large variance in the loss of life estimates. Priest (2009) in a review of applicability of UK methods to Europe noted that there is a tendency with most of the loss of life models to use catastrophic and extreme flood events (or dam break) for the establishment of the models. This can lead to some bias in the models.

Four potential loss of life models were reviewed as a part of this project:

- Jonkman (2008) – this method builds on previous work by Jonkman (2007) and uses data from hurricane Katrina in New Orleans. It proposed mortality functions for both breach zones (i.e., behind levee failure locations) and remaining areas. The remaining areas correlates the mortality rate with flood depth. It is understood that the mortality rate applies to the non-evacuated population
- Asselman and Jonkman (2003) – this method relates mortality for non-breach zones (i.e., behind a levee) with flood depth. The method was based on flooding from the 1953 floods in the Netherlands. As with Jonkman (2008), it is understood that this applies to the non-evacuated population.
- Graham (1999) – this method was derived for dam breach. However, WRL (2016) identified that it performed relatively well for floodplains as well. It relates several key factors such as warning time, flood severity and the relative understanding of flooding in the community and provides broad ranges of mortality.
- Wade et al. (2005) – this method, out of the UK (and is suggested in the UK MCM (2013) as well), was derived and is applied to studies in the UK. Unlike the above methods, it incorporates factors for vulnerable people (e.g., disabled and elderly), the type of flooding (warning times, rate of rise etc) and flood hazard (related to depth and velocity). This method was derived more specifically for floodplains and has been assessed across a range of floods. It also has the advantage of providing an estimate of the injuries rather than mortality alone.

To provide a comparison between the methods, they were estimated against the typical flood hazard zones within the AIDR (2017). These are shown in Figure 5. Mid-range values for each of the hazard categories were adopted, and conservative estimates (such as longer warning times) were assumed for each of the methods.

A comparison of the different methods is provided in Figure 6. Asselman and Jonkman (2003) and Jonkman (2008) both provide high mortality estimates, but as noted it is understood that the population at risk should be estimated on the remaining population (those who did not evacuate). Wade et al (2005) and Graham (1999) show some agreement at low levels of flood hazard, but Graham (1999) increases significantly for high hazard flows.

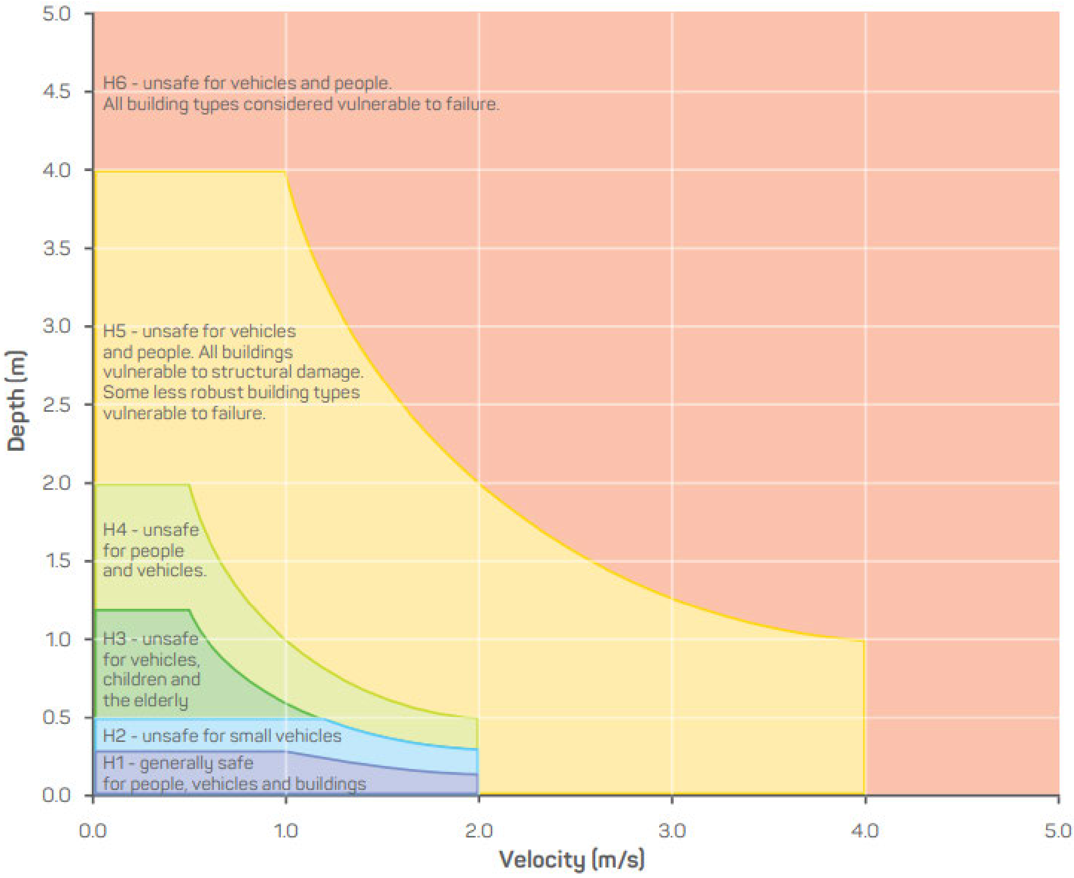

Figure 5. Flood Hazard

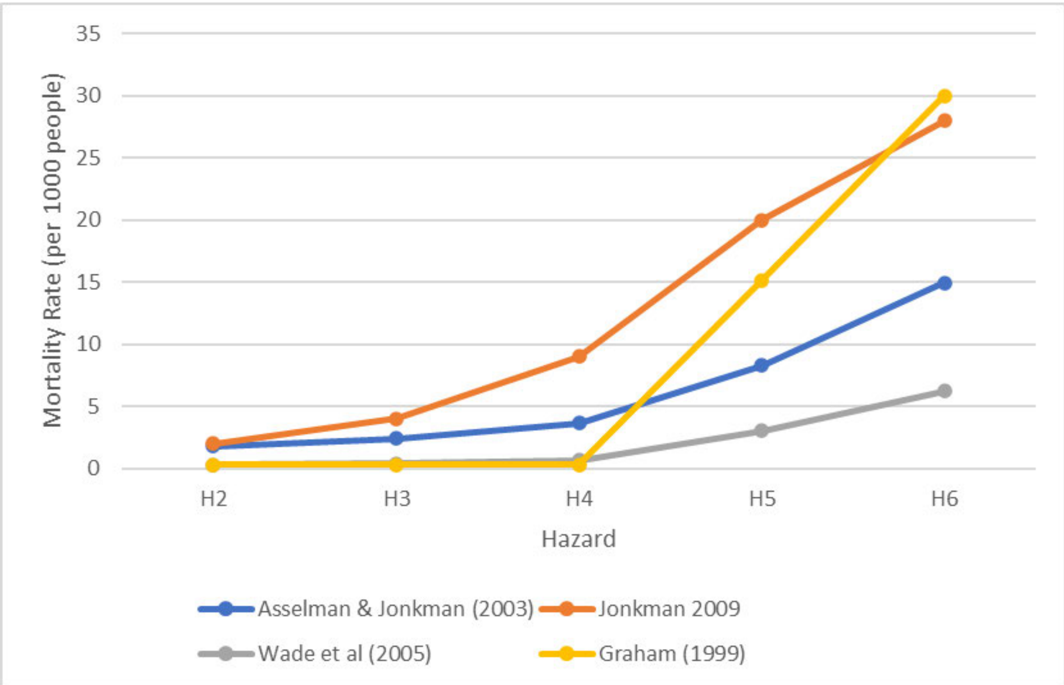

Figure 6. Comparison of Risk to Life Methods

Thomson et al (2021), in undertaking a review for NSW DPIE in the preparation of updated NSW guidelines, suggested the adoption of the Wade et al (2005) methodology. Given that this method would appear to provide a conservative estimate of the risk to life, as well as estimating injuries, this method has been adopted for this project.

Information available for each study area varies. The following approach was adopted:

- Estimate the approximate average flood hazard for each mesh block, based on either flood hazard mapping or depths, depending on availability of mapping, for the 1 in 100 AEP. In some cases, such as Katherine, flood depth information was relatively coarse and conservative methods were applied.
- Estimate the population at risk, adopting a population of 2.6 per household and estimating the number of households (based on the dwellings in the IAG database) impacted by flooding in the 1 in 100 AEP.
- Assume that there is no loss of life or injuries in events more frequent than a 1 in 20 AEP.
- Estimate the annual average value of lost life and injury assuming a linear increase in loss of life between 1 in 20 AEP and 1 in 100 AEP and assume no increase beyond that.

4.3 Other Intangibles

DEFRA (2004) undertook a research project into intangible damages from flood events in the UK. This involved national level willingness-to-pay surveys to recently flooded and 'at-risk' properties and focused on the intangible health impacts following the flood event. The results of the national survey confirmed "that flooding caused physical effects in the short term and psychological effects in the short and longer terms. Psychological effects included memory of the stress from flooding and damage, and the stress of recovering after an event, including that arising from settling claims with insurers and dealing with builders and repairers".

The research identified that the value of avoiding these intangible damages was roughly £200 per year per household (in 2004). There was no clear relationship between different types of households etc and this overall weighted value.

Using this information, and the survey results, the research established relationships between the value of avoiding impacts and the reduction in likelihood of being flooded.

To adapt this for Australian assessments, the following was undertaken:

- Conversion of all values into 2019 values, and conversion from UK pounds to Australian Dollars.
- Conversion of this information to reflect the willingness to pay to avoid overfloor flooding at different recurrence intervals.

The estimated damages per household per year is provided in Table 6. This shows the annual cost per household per year based on the threshold at which overfloor flooding occurs.

More recent work by Joseph et al (2015), also in the UK, undertook willingness-to-pay surveys as well, and focused on experience from flooding in the 2007 floods in the UK. Their survey was also more expansive, taking into consideration both health related as well as other intangibles at the household level. They estimated that the willingness-to-pay for households was approximately £650 per year per household in 2015. They also estimated the WTP to reduce psychological effects of flooding, which was approximately £260 per year per household, and not dissimilar to the DEFRA (2004) estimate. This suggests that the total willingness to pay was roughly 2.6 times just the health impacts.

Applying this ratio, the values in Table 6 were adjusted to account for these wider intangible damages. These have been adopted in this study. It is noted that overfloor flooding is not necessarily known, so instead the dwellings affected in each range of AEP event have been adopted as a proxy.

Table 6. Intangible Damage Estimate based on threshold event where overfloor flooding occurs – 2020 AUD values

Event ARI (years)	Event Probability (AEP)	Cost per Household per Year (based on Defra (2004))	Cost per Household per Year (adjusted based on Joseph et al (2015))
150	0.67%	$0	$0
125	0.8%	$8	$20
100	1%	$49	$123
75	1.33%	$175	$439
50	2%	$391	$981
30	3.33%	$520	$1,304
20	5%	$555	$1,392
10	10%	$574	$1,439
1	100%	$587	$1,472

4.4 Adopted Approach

Our estimate from the above explicit techniques for estimating intangibles suggests a lower estimate compared with the BMT WBM (2018) or the Deloitte (2021) studies.

Given the overall uncertainties, three intangible estimates have been provided in this study:

- Low Estimate – this estimate is based on explicit estimates as shown in the following sections. Given it is potentially conservative, this has been used for cost benefit analysis of the mitigation options for each short listed area.
- Mid-Level Estimate – based on the factors provided in the Brisbane River Flood Study (BMT WBM, 2018) and approximating the uplift factor based on the dwellings.
- High Estimate – based on the Deloitte (2021) estimate, adopting a 75% uplift factor.

Both the mid-level and high-level estimate have been used for comparative purposes when estimating the base case or existing damages for each of the short-listed study areas, to provide an understanding of the potential range and uncertainty associated with the intangible damages.

5 Climate Change

Three climate change scenarios were provided by IAG with their residential damage database:

- 0 degree warming, assumed to be representative of 2020 conditions.
- 2 degrees of warming. Based on advice from IAG, this scenario has a horizon of around 2040 to 2060, based on RCP4.5 and RCP8.5 (refer Figure 7). For this project, 2050 was adopted as representative.
- 3 degrees of warming. Similar to the above, this is representative of 2065 or later, depending on the RCP adopted. For this project, it was assumed to be representative of 2100.

The assumptions behind the methodology for estimating the residential damages and AAD that was undertaken by IAG for these scenarios is summarised in Dyer et al (2019). Further discussion on IAG's investigation of climate change influences in general are provided in Bruyere et al (2020).

For the economic assessment, a linear change in AAD was assumed between these periods for the residential data provided by IAG.

While the information was provided for the residential damages only, it was assumed that other damages estimated would increase at a similar rate.

This has been applied to both the base case and mitigation scenarios.

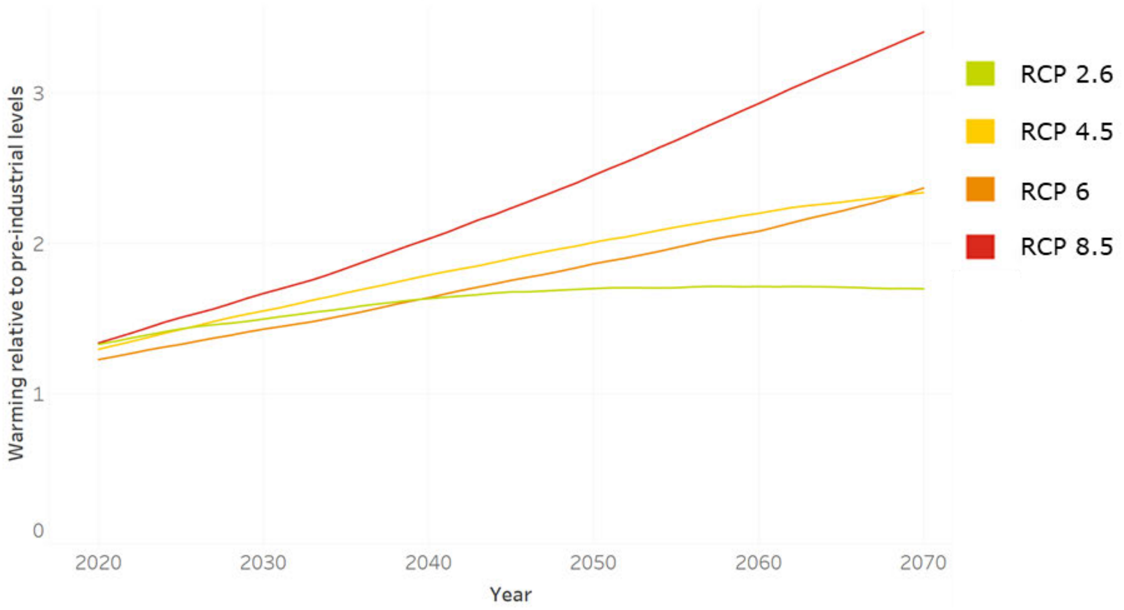

Figure 7. Forecast Warning based on Global Averages (Deloitte, 2021)

6 Comparison of Flood Damage Estimates

There are a number of assumptions that have been made as a part of the economic assessment for the different study areas. A comparison was undertaken on the estimates from this study, against available estimates from previous studies undertaken.

A comparison was undertaken with the recent study undertaken in Lismore by Engeny (2020). Engeny (2020) estimated the AAD for commercial and residential properties, and these were compared with the estimates for the current study. Engeny (2020) estimated their AAD values based on $0 damage in the 1 in 2 AEP. This is a relatively small event for damages to commence, and so this was recalculated based on a 1 in 5 AEP. The recalculated values, and the values from the current study, are shown in Table 7. The overall totals between the studies align fairly closely, although there are some differences between the residential and commercial damages.

Table 7. Lismore Study Area Verification - AAD

Source	Residential	Commercial	Total
Engeny (2020)	$14.8	$42.0	$56.8
Current Study	$30.0	$24.6	$54.6

Seymour had a flood assessment undertaken in 2001 (WBM, 2001) that quantified the annual average damages using both the RAM and ANUFLOOD. This appeared to quantify damages to residential and commercial/ industrial damages. A comparison of the 2001 study and the current estimate property damages is provided in Table 8. It shows a reasonable level of agreement, particularly between the RAM and the current estimate.

A further comparison was undertaken between the properties affected estimate from WBM (2001) and the current estimate. This is shown in Table 9. This shows reasonable consistency at the 1 in 100 AEP flood, although the current study would appear to have a lower estimate to the WBM (2001) study. However, this is expected to be due to the use of more up to date information or data.

Table 8. Seymour Verification - AAD Estimates[9]

Source	AAD Estimate
WBM (2001) – ANUFLOOD	$1.4M
WBM (2001) – RAM	$3.2M
Current Study	$3.6M

[9] Adjustment from 2001 to 2020 based on Average Weekly Earnings increases.

Table 9. Comparison of Number of Properties Affected

AEP	WBM (2001)	Current Study
1 in 100	288	301
1 in 50	282	253
1 in 20	277	155

7 Further Considerations

7.1 Unquantified Economic Impacts of Flooding

The focus of this assessment has been on the inclusion of readily identifiable and measurable economic impacts of flooding.

There are numerous economic impacts that have not been included within this analysis. Examples of these include:

- Agricultural impacts. Largely, the focus of this project has been on flood-affected townships and urban areas, rather than focusing on rural impacts. Therefore, these have not been included within the analysis.
- Environmental Impacts. The environmental impacts of flooding have not been included, as they are often complex and difficult to cost. Some impacts can be positive (inundation of wetland areas) while others can be negative (pollution of waterways). It has also been assumed that any negative impacts of any mitigation measures would be mitigated where possible.
- Indirect impacts on utilities and public infrastructure. While an allowance has been made for direct impacts on public infrastructure, indirect impacts (such as power outages) are not included. Similarly, traffic disruption both during and after the flood event are not included.

7.2 Limitations

The approaches adopted in this assessment are appropriate for strategic level economic estimation. Further detail and refinement would be required should the identified potential mitigation measures progress further.

The methodology adopted places a large degree of reliance on the underlying damages dataset provided by IAG. It has been assumed that this data is fit for purpose and representative of the damages for each area.

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Appendix C

Cost Estimates

Location	Name	General Description	Proposed Protection	Cost	Management Cost (10%)	Final Option Cost	Cost ($m)	Contingency Cost ($m)	Total with Contingency Cost ($m)
Shepparton	South Shepparton Levee	Earth levee, ~2m in height. One major road crossing. Levee length of around 4.3km long.	1 in 50 AEP	$ 8,850,000	$ 885,000	$ 9,735,000	$9.7		
	South Mooroopna Levee	Has two major road crossings. ~1 5m in height, total length around 2 5km long.	1 in 50 AEP	$ 3,502,500	$ 350,250	$ 3,852,750	$3.9		
	Kialla Levee	Open land, less constraints for construction. ~1 5m height. 0.6km long.	1 in 50 AEP	$ 630,000	$ 63,000	$ 693,000	$0.7		
	Boulevarde levee	Reasonably open earth levee, 1 major road crossing. ~1.5-2m in height, 4.9km long.	1 in 50 AEP	$ 7,167,000	$ 716,700	$ 7,883,700	$7.9		
	Kialla Lakes	Low levee ~1.5m in height, required road redesign. 1.3km long.	1 in 50 AEP	$ 3,172,500	$ 317,250	$ 3,489,750	$3.5		
	Riverside / Shopping Centre	~1m in height, 0 5km in length.	1 in 50 AEP	$ 240,000	$ 24,000	$ 264,000	$0.3		
	East Mooroopna Floodway	Roughly 64,000 m3 to be excavated and a large bridge widening on a major road. Identified in the SKM (2002) study to offset impacts of levees.	Increased conveyance of floodway	$ 2,718,000	$ 271,800	$ 2,989,800	$3.0		
			Total	**$ 26,280,000**		**$ 28,908,000**	**$28.9**	**$18.8**	**$47.7**
Narrabri	SE Levee	Earth levee ~2m in height, linking to the railway line, 1 road crossing, 1.8km	1 in 20 AEP	$ 4,539,443	$ 453,944	$ 4,993,387	$5.0		
	East Levee	Earth levee with some complicated sections, linking to rail line. ~2m high and 3 road crossings, 3.9km	1 in 20 AEP	$ 10,078,194	$ 1,007,819	$ 11,086,013	$11.1		
	Central Levee	Earth levee, ~1.5m high and 1 road crossing, 0.7km	1 in 20 AEP	$ 2,558,241	$ 255,824	$ 2,814,065	$2.8		
	Central Floodway Sth	Earth levee, ~1.5m high and 3 road crossings, 2.3km	1 in 20 AEP	$ 5,192,070	$ 519,207	$ 5,711,277	$5.7		
	Central Floodway Nth	Earth levee, ~1.5m high and 2 road crossings, 0.85km	1 in 20 AEP	$ 2,474,411	$ 247,441	$ 2,721,852	$2.7		
	West Levee	Earth levee, ~1.5m high and 2 road crossings (this levee may be difficult to implement), 1.6km	1 in 10 AEP	$ 3,625,473	$ 362,547	$ 3,988,020	$4.0		
	Industrial Levee	Earth levee, ~1.5m high and 2 road crossings (this levee may be difficult to implement), 1.9km	1 in 10 AEP	$ 4,089,288	$ 408,929	$ 4,498,217	$4.5		
			Total	**$ 32,557,119**		**$ 35,812,831**	**$35.8**	**$23.3**	**$59.1**

Location	Name	General Description	Proposed Protection	Cost	Management Cost (10%)	Final Option Cost	Cost ($m)	Contingency Cost ($m)	Total with Contingency Cost ($m)
Innisfail	South Innisfail	Earth levee, 0.5km long, requires a flood gate.	1 in 50 AEP	$ 1,581,577	$ 158,158	$ 1,739,734	$1.7		
	Goondi Hill Levee	Earth levee, 3.3km long, 2 road crossings.	1 in 50 AEP	$ 5,913,673	$ 591,367	$ 6,505,040	$6.5		
	Innisfail levee	Earth and concrete levee, 1.5km. Major road crossing and a flood gate.	1 in 50 AEP	$ 6,378,860	$ 637,886	$ 7,016,746	$7.0		
	Cullinane Levee	Earth levee, 3.1km long, includes a flood gate and multiple road crossings.	1 in 50 AEP	$ 5,642,416	$ 564,242	$ 6,206,658	$6.2		
	Dredging of Johnstone River - Large Scenario	Dredging of the river, not well scoped but may offset the increases due to levees.	Improved conveyance to off-set proposed levees	$ 9,500,000	$ 950,000	$ 10,450,000	$10.5		
			Total	**$ 29,016,526**		**$ 31,918,178**	**$31.9**	**$20.7**	**$52.7**
Rockhampton	South Rockhampton Levee	Large levee ~8 8km long, has an EAR completed (2019)	1 in 100 AEP	$ 80,360,000	$ -	$ 80,360,000	$80.4		
			Total	**$ 80,360,000**		**$ 80,360,000**	**$80.4**	**$0.0**	**$80.4**
Tweed	South Tweed Levee	Earth bank, 2 road crossings, Raise from 2mAHD to 2.8mAHD, 4.4km in length	1 in 100	$ 11,011,315	$ 1,101,132	$ 12,112,447	$12.1		
	Phillip Parade Ext	Earth bank, road crossings, one flood gate, build to 2.8mAHD, 1.4km in length	1 in 100 AEP	$ 6,030,495	$ 603,050	$ 6,633,545	$6.6		
			Total	**$ 17,041,810**		**$ 18,745,991**	**$18.7**	**$12.2**	**$30.9**
Dalby	Levee Ashmore Street	Earth bank levee, 3 road crossings, 8 8km, ~1-2m in height	1 in 100 AEP	$ 9,776,100	$ 977,610	$ 10,753,710	$10.8		
	Southern Flow Bypass	Large bypass, multiple properties impacted. Approximately 1m of earth excavated. Potential alternative lower capacity floodway.	Unknown	$ 48,993,119	$ 4,899,312	$ 53,892,431	$53.9		
			Total	**$ 58,769,219**		**$ 64,646,141**	**$64.6**	**$42.0**	**$107**
Seymour	Seymour Levee	Earth levee with large urban sections, 4 2km long, requires a multiple road crossings.	1 in 100 AEP	$ 20,000,000	$ -	$ 20,000,000	$20.0		
			Total	**$ 20,000,000**		**$ 20,000,000**	**$20.0**	**$5.0**	**$25.0**

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